Market Study to Determine Needs and Present Usage of Chemical Sensor Systems for Environmental Analytical Applications

Final Report

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Summary

Field measurement at environmental remediation sites can offer cost and time advantages over sample analysis at off-site laboratories. In order to realize this cost savings, the U. S. Department of Energy is attempting to accelerate the development of advanced field equipment. As a part of this effort, the current market for environmental field instrumentation was determined. The market analysis included discussions with equipment users, equipment vendors, and third-party sources.

Off-site independent laboratory analysis of samples from the site persists as the primary method of environmental analysis for site characterization, waste characterization, and process monitoring. Laboratory analysis is the preferred method of environmental analysis. This is because it is the reliable and accepted by regulatory agencies. Commercially available equipment for highly accurate field readings is perceived as being prohibitively expensive. Therefore, less precise field instrumentation is used to guide field investigations.

The primary field equipment used is the Gas Chromatograph, Photoionization Detector, and Flame Ionization Detector sensors. Other commonly used field technologies include Immunoassay kits, and X-Ray Fluorescence analyzers. Some instrument technologies which are commercially available but were rarely mentioned in the course of our interviews are fiber optic sensors, infrared/fourier transform infrared, piezoelectric sensors, and electrochemical sensors.

In 1996, the total U. S. market for environmental field instrumentation for site characterization, waste characterization, and remediation process monitoring is approximately $140 million. This market can be expected to grow at an average rate of 7% per year for the next 5 years.

Sixty-eight needs for new or improved instruments have been identified in the developing market for environmental instrumentation. The most significant need in terms of market potential is that of detecting organic compounds in an air matrix, closely followed by organics in soil. The potential for equipment which operates in-situ is higher than the potential for equipment which is extractive. The most significant need for field monitoring instrumentation was found to be monitoring organics in air.

Background

The U. S. Department of Energy's Office of Science and Technology is promoting the use of new technologies to accomplish waste cleanup and environmental remediation more cost effectively at DOE sites. One group of technologies identified with a potential for cost savings is those that allow characterization, monitoring, and sensing of environmental contaminants while in the field. Field deployable instrumentation can offer cost and time savings when compared with off-site laboratory analysis of field samples.

The goal of the Characterization, Monitoring, and Sensing Technology Crosscutting Program (CMST-CP) is to advance cost and time saving field instrumentation technologies. CMST-CP is responsible for assessing the commercially available technologies and encouraging the commercialization of new technologies for field deployable environmental analysis. Toward that end, the Ames Laboratory, in cooperation with the Department of Energy, commissioned a market study of chemical sensors and field instrumentation for environmental analytical applications.

The objectives of the study were to determine:

- what commercial instrumentation is currently being used for environmental analysis in the field;
- what environmental analysis field applications are most common;
- what environmental field instrument commercial markets are most attractive;
- what new capabilities for environmental field chemical analysis would be most valuable to users.

This report examines the market for field instruments from a number of perspectives. First, methods of environmental field analysis are considered, including alternatives to field instruments such as laboratory analysis, or field laboratories. The barriers to acceptance of field instruments in the marketplace are presented to illustrate what drives the market. Commonly used field instrumentation is presented with respect to their use, applications, and sales. Next, the buyers and sellers of field instruments give a more complete picture of the market for these instruments. The long-term market potential for selected instruments is evaluated. Finally, market needs as described by equipment users are presented, and ranked in terms of market potential.

When reading this document, it is important to keep in mind how it was developed. Facts and opinions of a number of environmental field instrument users within the DOE, users outside of the DOE, vendors, and other sources have entered into the analysis of the market, and the market needs. The source of this underlying information is an important consideration when judging and interpreting this report.

Methodology

The research for this report was conducted using a combination of commonly employed market research methodologies. Initial secondary research was provided by the DOE and collected from a number of other secondary sources. The thrust of the project was collection of primary research in the form of interviews of equipment users and equipment vendors.

In the course of the research, particular attention was paid to five focus areas of interest within the DOE. They are:

- Contaminant Plume Containment and Remediation Focus Area (PFA);
- Landfill Stabilization Focus Area (LSFA);
- High-Level Waste Tank Remediation Focus Area (TFA);
- Mixed Waste Characterization, Treatment, and Disposal Focus Area (MWFA);
- Facility Deactivation, Decommissioning and Materials Disposition Focus Area (DDFA).

Within these five focus areas, three particular types of tasks were of interest with respect to the application of field instruments – site characterization, waste characterization, and remediation process monitoring.

A significant amount of material was provided by the DOE as background for this project. A seven part evaluation of chemical sensor development conducted by the Hazardous Waste Remedial Actions Program (Hazwrap) of the DOE provided some vendors and technology developers of advanced instrumentation. The Office of Environmental Management Technology Development "rainbow books" provided a background of the activities of each of the focus areas. Technology Development Needs Summaries of each of the focus areas as well as supporting material provided was examined as a basis for the DOE user needs. A previous incomplete telephone survey of DOE user needs provided further background on needs with the DOE. The

EPA's Vendor FACTS database, released midway through the project, provided further information on technologies and vendors of field analytical equipment.

Additional secondary research material was collected from industry publications, books, periodicals, buyer's guides, and the internet. The complete list of citations is listed in the Bibliography and includes Pollution Engineering, The Environmental Business Journal, and other publicly available data sources.

Primary research was conducted by contacting equipment users and equipment vendors. As actual equipment usage information was desired, the emphasis was placed on user interviews.

In order to meet the project timeline, a decision was necessary between conducting a large number of standard interviews or a smaller number of in-depth, open-ended interviews. A smaller sample (30) of in-depth interviews was identified as having information gathering advantages for the purpose of the project. A number of trends and conclusions may be deduced from the interviews, and a number of insights were provided through user comments in open-ended discussions. A drawback of the smaller sample is that the results are not as statistically accurate as possible.

Over thirty equipment users were contacted in regard to the field instrumentation which they use, the manner in which it is employed, and the characteristics most desirable in new instrumentation. Since DOE equipment users had been contacted extensively, the focus of the interviews was on users of the equipment outside of the Department of Energy. Over thirty environmental consultants and other equipment users were identified and contacted.

Twenty interviews were conducted regarding the use of field instrumentation for site and waste characterization. The participants in these interviews were randomly sampled from several databases of environmental consulting and engineering firms based on size and region.[1] Particular attention was paid to ensure sampling of firms from arid and non-arid climates, as well as small, medium, and large firms. The objective of the interviews was to reach a user of field equipment or other individual with influence in the equipment's purchase and use.

Fourteen individuals were contacted regarding the use of field instrumentation for the monitoring of environmental remediation

[1]Sources include: PhoneDisc Business (Computer program). Bethesda Maryland: Digital Directory Assistance, September, 1995. *1994 Consultants' Guide*. Environmental Protection. October, 1994.

processes. Specific remediation processes were targeted from the U. S. Department of Energy's Commercial Environmental Cleanup directory as well as other directories. Processes targeted include soil washing, effluent monitoring, landfill stabilization, and facility decontamination. Of the fourteen process monitoring interviews, five potential users did not use field instruments, and two firms were no longer working in the particular environmental remediation process of interest[1] .

Environmental field instrument vendors were also contacted as primary sources for the project. Several vendors of each type of instrument encountered were contacted to provide equipment applications, market data, market trends, and other insights. A list of companies contacted during the course of this project is included in the Bibliography.

On occasions where different sources provided conflicting information, data was submitted to a third-party industry expert for reconciliation. All data sources were double-checked and documented for validity and future reference. Preliminary results of this market study were presented at a Workshop on the Commercialization of Chemical Sensors and Field Deployable Instrumentation for Environmental Applications and again at a Forum on Chemical Sensors for Environmental Applications as part of the 1996 Pittsburgh Conference and Exposition on Analytical Chemistry and Applied Spectroscopy in March, 1996. Comments on the study received at each of these events were incorporated into this final report.

A summary of the thirty user interviews has been provided as a part of this report. The interviews are divided into two parts. The results of twenty interviews which were directed toward users of site and waste characterization instrumentation are summarized on pages 1-5 to 1-31. The results of the fourteen interviews directed toward remediation process monitoring are summarized on pages 1-31 to 1-43. Each set of survey results are coded to ensure the anonymity of the participants. Each interview attempted to uncovered the activities of the participant, the field instruments used, and desired characteristics of improved field instruments.

[1] Two vendors had been listed in the Commercial Environmental Cleanup directory under soil washing, but were found to no longer provide this service.

Survey Results - Site and Waste Characterization Interviews

Interviews are coded with a number from 1 to 20. For each interview, the location of the company and title of individual interviewed are listed. To ensure the anonymity of the participants, the names of interviewees and their companies have been removed.

Nearly all of the interviews were with main or branch offices of environmental engineering or environmental consulting firms. An example of some of the firms contacted for interviews included Dames & Moore, Roy F. Weston, and CH2M Hill. A random sample of these firms yielded offices with between 10 to 600 employees. Most of the individuals work with a variety of industries on a number of projects at any given time, with a few specializing in government, chemicals, or petroleum industry sites.

The location of the establishment contacted and the title of the interviewee are listed below, coded from 1 to 20. These numbers are used to identify responses from the interviewees throughout this summary.

1. Illinois
   Staff geologist

2. New York
   Senior Chemist

3. Alabama
   Environmental Consultant

4. Missouri
   Project Manager for Air Monitoring

5. Missouri
   Project Manager

6. Utah
   Environmental Engineer

7. Massachusetts
   Group Leader, Equipment Services

8. Colorado
   Senior Engineer

9. Colorado
   Project Manager

10. Wisconsin
Senior Environmental Field Technician

11. Montana
Project Manager

12. Montana
Project Manager

13. Wisconsin
Senior Field Technician

14. Texas
Project Engineer

15. California
Environmental Chemist

16. Tennessee
Senior Geologist

17. North Carolina
Staff Engineer

18. Arkansas
Project Geologist

19. Pennsylvania
Project Manager

20. California
Project Geologist

Q1. a. Do you do work in contaminant plume containment and remediation? What percentage of your time is spent in this area?
b. How do you currently characterize plume containment and remediation sites?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. Yes, 20%.
b. Predominantly sampling but depends on site, occasionally geophysical testing too.
c. EM, gravimetric, that sort of thing
2)a. Yes, 70%.

b. Both sampling and field instruments, depending on contaminants.
c. Portable GCs (Gas Chromatography) and immunoassay kits. Both real-time, on-site response.
3)a. Yes, 5%.
b. Both sampling and field instruments, depending on the site
c. OVA (organic vapor analyzer) tubes, and occasionally field GCs.
4)a. No
5)a. Yes, 10%.
b. Use pump and treat systems, infiltration detection with trenches, horizontal wells, slurry walls.
c. Photo ionization (manufacturers Thermal Instruments, Microtip, OVM instruments). On site GC. Switching to "geo-probe"systems that have on-site, real-time capability. Samples also sent back to lab.
6)a. Yes, 80%.
b. Varies. Now about 30% is in the field, and 70% is conventional sampling.
c. Traditional PID/FID, Hack kit. Occasionally on-site labs with GCs.
7)a. Yes, No one can say exactly how much. (As equipment manager, he is answering for the Cambridge office, which does work in all areas).
b. There are lots of different ways. No one single way across the board. It depends on the contaminants.
c. It is all site specific. For general total organic compounds, FIDs/PIDs. If combustible gases might be a concern then combustible gas indicators will be used. There are scores of instruments which they use. You could categorize them or group them, but it would not be by application (Focus Area) but by contaminant. For fuel tanks you may also use FIDs/PIDs, but it depends on the fuel. The decision is made based on the contaminant, as well as the health and safety process. Another big input is the health and safety of the operator.
8)a. Yes, 30%.
b. We do everything. Come in at the beginning and sample soil, surface water, groundwater, etc.
c. Portable equipment to measure surface and groundwater parameters, oxygen, and pH levels. Company owns its own equipment brand named Oyster. Rents YSI equipment and other equipment from major manufacturers.
9)a. No
10)a. Yes, 80% now (Respondant included USTs as plume remediation).
b. Field instruments, and groundwater sampling. It depends on when we enter the picture, what part. Phase I investigation is

just visual and Phase II is drilling, identifying stuff and tank pulls, that sort of thing. Then they design the system, install the system, and finally maintain the system. (Based on the responses it appears that the only field instruments used were for sampling, and not for field analysis.)

c. Phase II - drilling rigs, geoprobes, soil boring. Sometimes monitoring wells are in place before they come on the scene. Then samples are sent to the lab. There's all kinds of equipment. Explosimeter, HNUs, OVMs, stuff like that. Air monitoring at the site to monitor releases from remediation. (Prompted with field instruments). Sure, GCs, immunoassays.

11)a. Yes, 5%.

b. Varies by conditions. Work off the middle of the plume. Do free product recovery (passive or active), intercepts, etc. Mostly work with smaller plumes in the residual phase, where there are low levels of migration.

c. "Petrofy Analysis", photoionization analysis with Microtip.

12)a. Yes, 30%.

b. Bring in a rig and drill. Samples are sent to the lab for analysis.

c. Temperature probes. PIDs. Heat analysis instruments. Brands are Photovac and Microtip.

13)a. Yes, 80%.

b. Both sampling and field instrumentation.

c. Probe for pH and conductivity; instruments to measure carbon dioxide and methane. (No models came to mind). Foxboro OVA for photoionization. MSA explosimeter to measure oxygen and toxicity. YSI's dissolved oxygen meter.

14)a. Yes, 30-40%.

b. Various methods. Classic monitoring wells, geoprobes, water sampling, even geophysics sometimes.

c. Water instrumentation for dissolved oxygen, redox. A Hydrolab probe does everything, you put it in a well and it measures for everything and gives you a digital readout with everything you need.

15)a. Yes, 30%.

b. For groundwater plumes it is all sampling. They use field instruments for pH, temperature, conductivity, to screen the stream, then they are sent to the lab for chemical analysis. For soil contaminants they use an organic vapor monitor (OVM) for screening, and again sent it to the lab.

c. Water instruments, OVM (Thermo Environmental)

16)a. Yes, <5%.

b. Combination of field screening with samples sent back to lab.

c. For vapor analysis, FID; replaces the old Foxboro. For PIDs, Microtip and Miniray. Do other types of analysis.

17)a. Yes, 10%.

b. Little of both sampling and field instruments.
c. It depends on the contaminants. Field instruments are mainly used for screening, and samples are always sent to the lab. They have taken labs on-site with GCs, but normally in the field they just take OVMs or PIDs with them.
18)a. No
19)a. Yes, but none personally. It is difficult to say as an office. It varies. Personally, he coordinates field equipment among other things.
20)a. Yes. As a geologist, he does more investigation. Engineers do feasibility, and remediation. It runs the gamut from landfill closure and groundwater contamination, USTs for fuel tanks, investigations for proposed landfills. Past waste practices can include buried drums, pesticide storage, PCB storage, and every type of waste practice which may affect the subsurface soil.
b. That depends on how quickly they need the results. They have some portable GCs, one Bruker, another manufacturer, and some field trailer labs with full scale instrumentation. On one project in the desert with VOCs, they had a portable lab for quick turnaround. They can focus the field investigation more closely. To answer the question, in general they use a combination of on-site and off-site labs. Field equipment offices have been set up. They have lots of rental contracts through a basic ordering agreement for everything from health and safety monitoring equipment to personal protective gear. Maybe not one supplier, but several suppliers. All determined before field mobilization. He is the equipment user depending on the equipment. PID, FID, a geologist would use. Hand augers, field exploration, groundwater sampler, temperature and conductivity probes would be geologist. The field analytical lab would require a chemist, only a chemist could operate that equipment.

Q2. a. Do you do work in landfill stabilization? What percent of your time is spent in landfill stabilization?
b. How do you currently characterize landfill stabilization sites?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. No
2)a. Not personally, others in company do.

3)a. Yes, less than 5%
b. Both sampling and field instruments, depending on the site.
c. OVA tubes, and occasionally field GCs.
4)a. No
5)a. No

6)a. No
7)a. See Q. 1
8)a. Yes, 5%
8b. Groundwater monitoring. Stabilize after closure to make sure contaminants are contained. Close and cap landfills, then monitor them.
8c. Generally use clients' equipment to monitor. Clients are usually manufacturing companies who dispose of their own waste. Keck is an instrument company they use that comes to mind.
9)a. No
10)a. No
11)a. Yes, but 0% personally.
11b. Company does monitoring for permits. Lab work rather than field instruments.
12)a. No
13)a. Yes, 5%
13b. Both sampling and field instrumentation.
13c. Probe for pH and conductivity; instruments to measure carbon dioxide and methane. (No models came to mind). Foxboro OVA for photoionization. MSA explosimeter to measure oxygen and toxicity. YSI's dissolved oxygen meter.
14)a. No, but we do permitting and montoring, 5-10% in the office is permitting and monitoring
b. Various methods. Classic monitoring wells, geoprobes, water sampling, even geophysics sometimes.
c. Hydrolab probe with digital readout.
15)a. Yes, sometimes, 5%.
b. Field screening then lab analysis. Might use a combustible gas indicator. OVM photoionization detector (Thermo Environmental)
c. Might use a combustible gas indicator. OVM photoionization detector (Thermo Environmental)
16)a. No
17)a. No, not recently.
18)a. Yes, 10%
b. Field monitoring of water wells. Samples sent to lab.
c. No brand of field instruments comes to mind.

Q3. a. Do you do work in waste tank remediation? What percent of your time is spent in waste tank remediation?
b. How do you currently characterize waste tank remediation sites?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. Yes, occasionally, 5%

b. Predominantly sampling but depends on site, occasionally geophysical testing too
c. EM, gravimetric, that sort of thing
2)a. Yes, 10-15%. Others at our company are 100%.
b. Both sampling and field instruments, depending on contaminants.
c. Portable GCs (Gas Chromatography) and immunoassay kits. Both real-time, on-site response.
3)a. Yes, 2%
b. Both sampling and field instruments, depending on the site.
c. OVA tubes, and occasionally field GCs. Also immunoassays.
4)a. No
5)a. Yes, Less than 10%
b. Evaluate with tank testing, audit records of spillage and so forth. Records of fuel in and out of tank, subsurface monitoring.
c. Same as for plume containment. (Photoionization by Thermal Instruments, Microtip, OVM instruments. On-site GC. Lab analysis.) Immunoassay tests used for petroleum and PCBs. Also use lower exposure meters for subsurface work to protect employees from hazardous environment.
6)a. No
7)a. See Q. 1
8)a. Yes, 5%
b. Present at tank pulls, then monitor the soil at the excavation.
c. Photoionization detectors for soil. Company owns detectors from Environmental Instruments. Also use methane detectors and oxygen meters. Rent equipment from "H News". Might also add hydrocarbon test kits (Immunoassays) from Ensys.
9)a. No
10)a. Yes (See Q.1)
11)a. No
12)a. No
13)a. Yes, 15% or less
b. Tank pulls and soil testing around the excavation.
c. Probe for pH and conductivity; instruments to measure carbon dioxide and methane. (No models came to mind). Foxboro OVA for photoionization. MSA explosimeter to measure oxygen and toxicity. YSI's dissolved oxygen meter.
14)a. Yes, 10-15%
b. Various methods. Classic monitoring wells, geoprobes, water sampling, even geophysics sometimes. Sometimes we will do field screening with a field GC, and back it up with samples.
c. Field GC.
15)a. Yes, 5%
b. Field screen, lab analysis

c. Might use a combustible gas indicator. OVM photoionization detector (Thermo Environmental)
16)a. Yes, 5%
b. Field screening with samples sent back to the lab.
c. FID. Field GC and soil gas analysis through subcontractor. Not familiar with subcontractor's instruments.
17)a. Yes, a lot, 60%
b. Mostly sampling.
c. It depends on the contaminants. Field instruments are mainly used for screening, and samples are always sent to the lab. They have taken labs on-site with GCs, but normally in the field they just take OVMs or PIDs with them.
18)a. No

Q4. a. Do you do work in solid hazardous waste characterization, treatment, and disposal? What percent of your time is spent in waste characterization, treatment, and disposal?
b. How do you currently characterize waste characterization, treatment, and disposal sites?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. Yes, 20%
b. Predominantly sampling but depends on site, occasionally geophysical testing too
c. EM, gravimetric, that sort of thing
2)a. No.
3)a. Yes, Some large EPA contracts here, about 15%
b. Not too familiar with this area, but expect it is the same, both field and lab work.
4)a. No
5)a. Yes, 20%
b. Detect organic materials using photoionization detectors. Detectors become user friendly quickly.
c. Same as for plume containment. (Photoionization by Thermal Instruments, Microtip, OVM instruments. On-site GC. Lab analysis.)
6)a. No
7)a. See Q. 1
8)a. Yes, 20%
b. Generally the client is a manufacturing facility with hazardous waste. Company samples soil, sludge, groundwater. Monitors bioremediation. Client personnel usually monitor pH, temperature, and soil moisture.
c. Use client's equipment. Will use company equipment mentioned earlier (Oyster, Environmental Instruments, etc.)

9)a. Yes, 30%
b. Sample the media and send samples back to the lab. Do field screening for pH, conductivity, PIDs.
c. Foxboro 121, Microtip 2
10)a. No
11)a. Yes, 3%
b. Mostly lab work.
c. If VOCs are present, may use photoionization. May use instruments to detect metals and solvents.
12)a. Yes, 10-15%
b. Bring in rig and drill. Samples are sent to the lab for analysis.
c. None, but would like to afford a gas chromatograph (GC)
13)a No
14)a. No
15)a. Yes, 5%
b. Field Screen, lab analysis
c. Might use a combustible gas indicator. OVM photoionization detector (Thermo Environmental)
16)a. Yes, 90%
b. Field screening with samples sent back to the lab.
c. FID for vapor analysis. PIDs (Microtip and Microray). Field GCs. Subcontractor.
17)a. Yes, 20%
b. Occasionally field screening but always sampling.
c. It depends on the contaminants. Field instruments are mainly used for screening, and samples are always sent to the lab. They have taken labs on-site with GCs, but normally in the field they just take OVMs or PIDs with them.
18)a. Yes, 5%
b. Sampling. Samples sent back to lab.
c. Do not really use them.
19)a. Yes, It is difficult to say
b. FIDs, PIDs, sampling. All of that depends on the site. He is not aware if they have a percentage breakdown anywhere. It is the same equipment and techniques for site characterization and waste characterization.
c. PIDs, FIDs. Heath, miniray, OVA. He is not sure if those are company names or equipment brand names.

Q5. a. Do you do work in facility deactivation and decommissioning? What percent of your time is spent in facility deactivation and decommissioning?
b. How do you currently characterize facility deactivation and decommissioning sites?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. Not personally
2)a. No.
3)a. Yes, 5%
b. Field sensing or sampling.
c. OVA tubes, and occasionally field GCs. Also immunoassays.
4)a. No
5)a. No
6)a. No
7)a. See Q. 1
8)a. No
9)a. Yes, DOD facilities, 5%
b. Same as for hazardous waste. Sample the media and send samples back to the lab. Do field screening for pH, conductivity, PIDs.
c. Foxboro 121, Microtip 2, YSI model for water, "Hidak" for pH
10)a. No
11)a. No
12)a. No
13)a. Yes, 5%
b. Sampling and field instrumentation.
c. Probe for pH and conductivity; instruments to measure carbon dioxide and methane. (No models came to mind). Foxboro OVA for photoionization. MSA explosimeter to measure oxygen and toxicity. YSI's dissolved oxygen meter.
14)a. Yes, Government DoD and EPA sites, 5-10%
b. More site characterization type work, investigation not remediation. It also varies. It could be the same as the other (monitoring wells, etc.) but with some different stuff such as an XRF (x-ray flourescence detector for metals).
15)a. Yes, 5%
b. Field screen, lab analysis
c. Might use a combustible gas indicator. OVM photoionization detector (Thermo Environmental)
16)a. Yes, 75% (presumably overlaps with 90% on hazardous waste characterization)
b. Field screening with samples sent back to the lab. Also do geophysical sufrace logging using direct push and other techniques. Use drill rigs in some cases.
c. FID, PIDs, GCs. Subcontractor. Additionally multiple gas indicators.
17)a. Yes, 5%
b. Same
c. Same
18)a. No

Q6. a. In what other areas do you personally work? What percent of your time is spent in this area of work?
b. How do you currently characterize sites in each area?
c. What field instruments do you use? What feature(s) of this instrumentation make it most useful?

1)a. Mostly Phase II investigations. Not remediation but defining a plume in groundwater or soil. 50/50 between active vs. inactive site (operating facility or Superfund type closed facility.)
b. Predominantly sampling but depends on site, occasionally geophysical testing too
c. EM, gravimetric, that sort of thing
2)a. Ecological toxicity and risk assessment. 15-20%.
b. Both sampling and field instruments, depending on contaminants.
c. Portable GCs (Gas Chromatography) and immunoassay kits. Both real-time, on-site response.
3)a. Asbestos abatement, 3-5%. Lead abatement 3-5%. Water and waste water treatment about 10%. Also air monitoring, industrial hygiene. Remediation involves personnel and area air monitoring.
b. Both sampling and field instruments.
c. XRF for lead. There is a host of ways to do air monitoring, and that depends on the job. Includes field GC and OVA (Organic Vapor Analyzer).
4)a. Air monitoring, 100%
b. Depends on the kind of contaminants.
c. Extensive experience with all instrument, but currently own and use ETG (Environmental Technology Group) model MDA. It does remote sensing based on open path/infrared detection of gases in the air.
5)a. Primarily work at RCRA facilities. 50-60%
b. Determine if chlorinated solvents, metals, pesticides, and herbicides are present.
c. Same as for plume containment. (Photoionization by Thermal Instruments, Microtip, OVM instruments. On-site GC. Lab analysis.) Lab work is used to detect tougher contaminants like pesticides and herbicides. Immunoassays for PCBs.
6)a. Water, transportation, NEPA. Do not require site characterization.
7)a. See Q. 1
8)a. Some wastewater works but clients monitors and company interprets the data for them. They do not do air monitoring.
9)a. Personally, no others which involve characterization.
10)a. Foundry remediation, 20%

b. Same type of investigation. First we find out if there is contamination. Then it varies by whether the site is active or closed. If active we consider what chemicals they currently are using. There is Phase I investigation and then Phase II on-site characterization.
c. It depends on what type of contamination is present. Some sites do not have gasoline, they may have chlorinated compounds or whatever.
11)a. Already mentioned most of them (solid waste, hazardous waste, landfills - mostly at petroleum sites).
12)a. Surface water quality, 40%
b. Measure for pH and so forth. Samples are taken and sent to the lab.
c. Orion comes to mind.
13)a. None
15)a. Data validation, subcontracting, field sample plans, documentation, nothing which requires field analysis.
16)a. None
17)a. It depends. Some computer modeling to assess a plume - they have different graphics where they can put a monitoring well into the model to see what type of remediation they might use.
18)a. Ground water. Over 50%
b. Samples sent back to lab.
c. Do not use field instruments

Q7. a. Do you expect your company to purchase field instrumentation equipment in the next 12 months?
b. For what reason(s)?
c. Do you plan to spend: less than $50,000
between $50,000 and $100,000
between $100,000 and $500,000
more than $500,000

1) No. Normally they like to rent equipment or subcontract assessment services
2) No, just bought a new GC. Old one was old (obsolete).
c. Spent $20,000.
3) Yes, almost certainly will. Both replacing older equipment, and company growth. Not new regulations.
c. Not sure, probably between $50,000 and $100,000.
4) No, but it depends on the number of projects.
5) Yes. Replacement such as broken instruments, and additional instruments. Expansion of instrument collection.
c. Less than $50,000
6) Possibly. New technology or increased regulatory acceptance.
c. No idea how much it might be.

7) Yes. Not due to regulations but to replace older equipment, growth of the company, and new technology developments.
c. Probably less than $100,000.
8) Yes. Replace old equipment
c. Less than $50,000
9) No. Company perfers to rent rather than purchase
10) Yes. Because we need them. Due to growth.
c. No idea. I haven't looked at the prices of explosimeters or OVMs, so I do not really know.
11) No
12) Yes. Wear and tear on equipment
c. Less than $50,000
13) Yes. As more employees are added to the company, more instruments are needed. Also replacing and updating instruments.
c. Less than $50,000
14) No
15) No. Company does not spend.
16) No. Company prefers to rent to avoid upkeep and maintenance.
17) I doubt it.
18) No
19) Yes. Expansion
c. Around $80,000 in his office which is all he is concerned with.
20) No. Because it is all rented. The Navy contract has everything purchased project specific, but it is rented for the duration of the project, then the Navy owns it at the end. Sometimes it is turned over to the next contractor.

Q8. a. Are there occasions where you would like to have characterized a site while you were in the field, but were required to send samples to the lab?
b. Why were you unable to characterize the site in the field?
c. If equipment were available that overcame the limitation(s), would you purchase it?

1)a. Usually they budget the characterization out. Sure, sometimes he would want to but frequently the budget does not allow it - considered superfluous. Too much money. In remediation it is the other way - you need to rigorously define the plume, so you spend the money to characterize the site.
b. Cost
c. No. It is the practice of his company to rent equipment or subcontract out the service, but if the cost of rental fell, yes, they would probably rent it more often.

2) No. Generally, there is a reasonable characterization plan beforehand. With lab char or field char with 10-15% lab confirmation.
3)a. Yes.
b. Specific instances do not come to mind, but in general it is because equipment was not available. Sometimes the equipment does not exist, and it does exist, and we own it, but it is in use at another site.
c. Sure.
4) No. Due to the nature of instrumentation (for air monitoring) there is no need for lab work.
5)a. Yes.
b. Depends on the nature of the contaminant. Pesticides, metals, herbicides are hard to detect in the field. Regulatory demands for analysis are also a factor.
c. Potentially, yes. Depending on the reliability of the equipment.
6)a. Yes
b. Regulator confidence in the method.
7)a. Yes, almost always.
b. Regulators do not accept field analysis.
c. Possibly. It depends. There are cost issues. For example, immunoassay kits are out there which can be done in the field but the cost may be higher than laboratory analysis. It depends, particularly on your time requirements; do you need the results right away or can you wait for the results from the lab?
8) No. Technology has advanced so quickly, such as for testing for soil gases on-site, that there is no need for lab work.
9)a. Yes
b. Quality of field screening results were not comparable to sending samples to the lab.
c. Company prefers rental. Might consider purchasing if the equipment were reliable.
10) Well, no. It is not possible. The state of Wisconsin requires analytical report. What field detection we do use - gas detection for air and geoprobes usually have a field GC attached - helps give them an idea of what is at the site, but they still require lab analytical reports from registered labs and all of that.
11)a. Yes
b. While it is good to get as much data as possible, you must consider the cost of the equipment and how often it would be used.
c. Yes. They would buy equipment if it were cheaper, especially for lead detection at petroleum sites.
12) Yes
b. Field analysis is too limited. Could not collect data on specific chemicals. Good equipment is too expensive.

c. Yes, probably. Would like to have a portable GC and immunoassay kits, if they were more affordable.

13)a. Yes

b. Needed more detailed analysis than could be provided by field instruments

c. Possibly, if it were field worthy.

14)a. Yes, I guess.

b. I don't know. We haven't had the newest technology, forced to do sampling. It might be money, or time, or regulators, all sorts of reasons.

15) No

16) No. Company uses both field work and lab work and that seems to be adequate.

17)a. Yes

b. Normally due to North Carolina regulatory standards - they have to send samples to the lab. Especially underground storage tank sites require analysis.

c. Certainly think so, if the cost was less which I would expect it to be.

18) No

19)a. Yes

b. They needed a more definitiev answer than field instruments could give. They want to know exactly what is there and field equipment does not give that.

c. Probably not. It is too expensive for what they want. Labs would be cheaper and easier.

20) No. A situation where they require characterization immediately, where they do not want to wait, they use on-site labs. Some projects where he has not been involved that he knows of they have done that. They always have confirmation at an off-site lab, but can do a good portion at the site.

Q9. Please rate the following potential characteristics of environmental field analytic instruments on a scale from 1 to 5 where 1 is not important, 2 is somewhat important, 3 is average importance, 4 is very important, and 5 is urgently important. Keep in mind that the next set of questions is not about what equipment you currently use, but about what equipment you would like to see brought to market.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *	Other
a. In-situ sensing		✔✔✔	✔✔✔✔✔✔	✔✔✔✔✔✔	✔✔✔	***	3.5
b. Real-time sensing		✔	✔✔✔✔✔	✔✔✔✔✔✔✔✔	✔✔✔✔	*****	4.5
c. Continuous (unattended) monitoring	✔	✔✔	✔✔✔✔✔✔✔✔✔✔	✔✔	✔✔	***	4.5, n/a
d. Less expensive monitoring	✔		✔✔✔✔✔✔	✔✔✔✔✔✔	✔✔✔✔✔	****	4.5, 4.5
e. Improved operator safety		✔✔✔	✔✔✔✔	✔✔✔✔✔✔✔✔	✔✔✔	***	2.5
f. Increased resolution		✔	✔✔✔✔✔✔	✔✔✔✔✔✔✔✔✔✔	✔✔	**	
g. Remote operation	✔✔	✔✔✔✔	✔✔✔✔✔✔✔✔	✔✔✔✔✔			
h. Easier operation		✔	✔✔✔✔✔	✔✔✔✔✔✔	✔✔✔✔✔✔	*****	3.5
i. Improved regulator/ public acceptance		✔✔	✔✔✔✔✔	✔✔✔✔✔✔✔	✔✔✔✔	******	n/a
j. Decreased secondary waste generation (samples/prep)	✔	✔✔	✔✔✔✔✔	✔✔✔✔✔✔	✔✔✔	**	4.5, n/a
k. Smaller/ more lightweight		✔✔✔	✔✔✔✔✔✔✔✔✔✔✔	✔✔✔✔	✔	*	
l. Integrity verification			✔✔✔✔	✔✔✔✔✔✔✔✔	✔✔✔✔✔✔	*****	n/a
m. Improved temperature range operation		✔✔✔	✔✔✔✔✔✔✔✔	✔✔✔✔✔✔	✔	*	3.5
n. Improved resistance to moisture		✔	✔✔✔✔✔	✔✔✔✔✔✔✔✔✔✔	✔✔✔✔	***	
o. Improved sensing of contaminants in air		✔✔	✔✔✔✔✔✔	✔✔✔✔✔✔✔✔✔✔	✔	*	

Top 3-5 is checked for the number of times which the feature was mentioned as the top 3 to 5 most desirable features in Questions 11-16.

Other responses include not applicable or no opinion. When a multiple answer was given such as "3 or 4", the mean was entered, "3.5" in this case.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *	Other
p. Improved sensing of cont. in water		✔	✔✔✔✔	✔✔✔✔✔ ✔✔✔✔✔ ✔	✔✔✔	* *	
q. Improved sensing of cont. in sludge		✔✔	✔✔✔✔✔ ✔✔	✔✔✔✔✔ ✔✔	✔	* *	4.5, n/a
r. Improved sensing of contaminants in soil			✔✔✔✔	✔✔✔✔✔ ✔✔✔✔✔ ✔✔✔	✔✔	* *	
s. Improved subsurface soil sensing			✔✔✔✔✔	✔✔✔✔✔ ✔✔✔✔✔ ✔✔	✔✔	* *	
t. Improved sensing of contaminants in concrete/ metal pipes/ other solid materials	✔✔ ✔✔	✔✔✔✔ ✔✔	✔✔✔✔✔	✔✔✔			n/a
u. Extended sensor life	✔	✔	✔✔✔✔✔ ✔✔✔✔	✔✔✔✔✔ ✔✔✔		*	
v. Improved Detection of radioactive contaminants	✔✔ ✔✔	✔✔✔	✔✔✔✔✔	✔✔✔✔✔			0, n/a, n/a

Top 3-5 is checked for the number of times which the feature was mentioned as the top 3 to 5 most desirable features in Questions 11-16.

Other responses include not applicable or no opinion. When a multiple answer was given such as "3 or 4", the mean was entered, "3.5" in this case.

Note: Interview #15 answered 4 to all items o. to t. as they are all equal in his mind.

If 4 or 5: *to v:*

Which radioactive contaminants?	Yes
Transuranics (TRU):	✔
Cesium-137 -	
Strontium -90 -	
Plutonium -	✔
Uranium -	✔✔✔
Other (specify) -	

13) Don't know specifically, "maybe all of them".
15) Not sure which uranium isotopes. Radium 226

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
w. Improved detection of metals	✔		✔✔ ✔	✔✔✔✔✔✔✔✔✔ ✔✔✔✔✔	✔	* *

4) Respondent not familiar with metals detection (air monitoring)

If 4 or 5: to w:

Which metals?	Yes
Mercury -	✔✔✔✔✔✔
Lead -	✔✔✔✔✔✔✔✔✔
(Hexavalent) Chromium -	✔✔✔✔✔✔✔✔
Arsenic -	✔✔✔✔✔✔✔✔
Nickel -	✔✔✔✔✔
Cadmium -	✔✔✔✔✔

2) RCRA metals - Cr, As, Ni, Na, Si, Pb
3) With emergency response, you never know what pollutants you might need to detect
7) Lead in particular
9) All of the RCRA top 8
12) Copper and Zinc
14) Lead is a big one. All of them, really.
15) Lead, Chromium and Arsenic were "yes". Mercury, nickel and cadmium to a lesser extent.
17) RCRA metals, especially mercury and lead.
18) All of the above
20) For groundwater, elements such as Ni, Cu, low mcl, Ar, Pb, Cr, Cd. It is more important in groundwater for situations where there are lower mcls contaminants there are tough lines. In soil you have rvcs.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
x. Improved detection of organics			✔✔	✔✔✔✔✔✔✔✔✔ ✔✔✔✔✔✔✔	✔	

If 4 or 5: to x:

Which organics?	Yes
Polychlorinated Biphenyls (PCBs) -	✔✔✔✔✔✔
TCE -	✔✔✔✔✔✔
TCA -	✔✔✔
Perc -	✔✔
Freon-133 -	✔
Carbon Tetrachloride -	✔✔✔✔
Chloroform -	✔✔✔
Toluene -	✔✔✔✔
Benzene -	✔✔✔✔

1) Total VOCs in general
2) Semi-volatiles need improvement. Volatiles are easy to detect now.-
3) Can be anything.

6) Solvents in general. Semi-volatiles are tough, and even the volatiles have been sort of late in coming to market due to regulatory acceptance.
7) None in particular. (later) TCE.
8) Hydrocarbons in general
9) All petroleum based organics and chlorine containing organics.
11) Heavy hydrocarbons as a group.
12) All volatiles as a group.
13) BTEX (benzene, toluene, ethyl benzene, xylene)
14) Chlorinated compounds.
15) Chlorinated compounds.
16) BTEX, chlorinated solvents.
17) They run 82/60 for the volatiles and 82/70 for the semi-volatiles, so about the whole list.
19) In general. When we go out we look for organics.
20) For immunoassay field screening kits, PCBs, pesticides at lower concentrations.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
y. Improved detection of other pollutants	✔		✔✔✔✔✔✔✔✔	✔✔✔✔✔✔✔✔✔✔✔		*

If 4 or 5: to y: Which other pollutants? Yes

Which other pollutants?	Yes
Nitrates -	✔✔✔✔✔
Cyanide -	✔✔✔
Ferrocyanide -	✔✔✔
Phosphorus -	✔✔✔
Sulfur -	✔✔
Noble metals -	
Dense Non-Aqueous Phase Liquids -	✔✔✔✔✔

2) Pesticides
5) Pesticides, herbicides
11) Chlorides
13) Pesticides and herbicides
16) Semi-volatiles, pesticides (DDT, etc.)

Q10. Can you think of other ideal product features I have not mentioned?

1) Resistance to moisture (this was added as item n. due to this suggestion)
2) No. You pretty much covered them. A lot of the features listed are general, with some machines meeting the needs and others not.
3) No, they are all there.
4) Better detection levels (f). It would help to be able to measure levels required for regulations.
5) Storage of information collected. Downloading of data.
6) No
7) No. Too general
8) Clients that are not familiar with field equipment do not find it easy to operate. Equipment should be more resistant to breakdown to contaminants, such as in water when the instrument is not sealed.
9) No. List seemed comprehensive
10) No.
11) No
12) Data logging abilities. Hard to transfer data to PCs.
13) Sturdy.
14) No.
15) Easy to calibrate, longer battery life, more rugged, ability to download to computer.
16) Easier to understand manuals.
17) Nothing that I can think of.
18) No
19) Not that I can think of.
20) The equipment is getting pretty sophisticated out there now. I can't think of any product feature that hasn't already been invented that has applications that hasn't been addressed already off the top of my head.

Q11. Of all of the characteristics, could you select 3 to 5 which are the most important or most urgent but are not commercially available in existing equipment?

1) About 8: Real-time sensing, less expensive, safety, resolution, temperature range, water, soil, subsurface soil.
2) Real-time sensing, improved detection in soil, extended sensor life.
3) Sensing of contaminants in air, soil, subsurface soil.
4) Real-time sensing, easier operation, integrity verification.
5) Improved detection of metals and other non-organics. Improved regulatory acceptance.

6) Sensitivity. Operator skill/ease of use. Regulator acceptance.
7) Less expensive. Easier operation. Improved regulator acceptance. Integrity verification.
8) Unattended monitoring. Less expensive monitoring. Easier operation.
9) Improved regulator acceptance. Decreased secondary waste. Integrity verification.
10) Less expensive monitoring. Improved operator safety. Integrity verification (quality).
11) Improved sensing of contaminants in soil. Improved sensing of contaminants is water. Improved temperature range operation.
12) Increased resolution. Improved sensing of contaminants in water. Improved sensing of contaminants in sludge.
13) Improved resistance to moisture. Improved temperature range operation. Smaller/ more lightweight.
14) Real-time sensing. Improved operator safety. Improved regulator acceptance. Decreased secondary waste generation.
15) In-situ sensing. Real-time sensing. Increased resolution. Improved public acceptance. Improved detection of metals.
16) In-situ sensing. Real-time sensing. Easier operation. Improved resistance to moisture.
17) Integrity verification. Regulatory acceptance.
18) Improved sensing of contaminants in sludge. Improved sensing of contaminants in water. Improved subsurface soil sensing.
19) Less expensive. Improved operator safety. Easier operation. Improved resistance to moisture.
20) In-site sensing. Real-time sensing. Continuous monitoring.

Q12. a. (The first of the 3-5 top needs) For ____, in which area of your work do you most need this feature?
b. What are the inadequacies of the current equipment in this respect?

1)a. Less expensive. All areas
b. Could be less expensive
2)a. Real-time sensing. Needed for remediation.
b. It depends on the equipment. Some equipment is good in real-time, some is not.
3)a. Sensing of contaminants in air.
b. It would increase safety.
4)a. Real-time sensing. Air monitoring
b. Instruments that are good in real-time are not good at detection.
5)a. Improved detection of metals and other non-organic compounds. Site investigation in all areas mentioned earlier.
b. No field screening instruments for detection of metals and other non-organics is available.

6)a. Sensitivity. Plume containment and remediation.
b. Could use better sensitivity.
7)a. Less expensive.
b. If you could produce a more cost effective product, obviously it would gain acceptance.
8)a. Unattended monitoring. Smaller, remote sites such as gas stations for waste tank remediation.
b. Equipment frequently breaks down. It is not very reliable.
9)a. Improved regulator acceptance. Hazardous waste characterization.
b. Quality of the data from field screening is not adequate. Makes it hard to build a defensible case from field data.
10)a. Less expensive monitoring. Both plume remediation (including USTs) and foundry remediation.
b. Well, its expensive but its because of the market. Most companies are competitive because usually there are several bids. But it is expensive. A lot of times Ma & Pa gas stations have gone under because they can not afford the fees of cleaning up, so low cost is important.
11)a. Improved sensing of contaminants in soil. Plume containment and hazardous waste.
b. Present equipment has limited range and often detects only a single contaminant.
12)a. Increased resolution. Ground water analysis.
b. There is no immediate sense of the contaminants in a well. Field screening methods provide parts per million which is not as good as what lab analysis can provide. Would like to see field instruments that can provide a better range.
13)a. Improved resistance to moisture. Plume containment.
b. Some field instruments are not built for actual field conditions.
14) Real-time sensing. All.
15)a. In-situ sensing. Soil characterization of surface soil.
b. More for XRf, later models are O. K. but earlier models are not. The hypothetical question is what was most important, and in-situ is very important, but newer instrumentation is in-situ.
16)a. In situ sensing. Soil and ground water, mainly in hazardous waste work.
b. Only one thing on the market, believe it is infrared instrument that sends out a pulse. Can detect BTEX (benzene, toluene, ethyl benzene and xylene) compounds, but its bad for clorinated solvents. Need DPH analyzers.
17)a. Integrity verification. In general.
b. If the results aren't dependable then they are no good.
18)a. Improved sensing of contaminants in sludge. Water area.
b. Resolution of current (sludge characterization) equipment is poor.

19)a. Less expensive monitoring. Underground Storage Tanks. Regulators only pay so much for their state's UST reimbursement program, so the cheaper the equipment is, the easier it is to get reimbursed.
b. There are not any, because he is happy with what they have got. Very precise equipment is very expensive.
20)a. Continuous monitoring. In general.
b. The reason that I mentioned continuous monitoring was that it could eliminate some operator variation for different crews. You could possibly get different readings due to just about anything; purging, calibration, sampling criteria, if a pump is on or off. Continuous monitoring might eliminate operator error.

Q13. a. (The second of the 3-5 top needs) For ____, in which area of your work do you most need this feature?
b. What are the inadequacies of the current equipment in this respect?

1)a. Improved temperature range. All areas.
b. Does not operate at all temperatures
2)a. Improved detection of contaminants in soil. Remediation. Real-time detection of metals in soil is the biggest one. Other than x-ray diffraction there is no alternative, and it has its limitations.
b. Current equipment (X-ray diffraction) is available, and transportable, but it is the only option.
3)a. Improved sensing of contaminants in soil.
b. It would reduce costs and time.
4)a. Integrity verification. Air monitoring.
b. For many systems, there is no means of verification. Real-time instruments can't verify. Present instruments have a quality assurance cell to verify gases. Can put one gas in at a time, but at the site it is expensive to verify for 25 to 30 gases. Hard to determine mixtures.
5)a. Improved regulatory acceptance. Site investigation in all areas mentioned earlier.
b. (improved regulatory acceptance...) would save money and time if instead of 500 samples you could take only 50. Real-time is not always acceptable. Much lab work has to be done, with lots of time spent on guessing (plot contaminants, guess how to shrink the grid, take more samples, guess again).
6)a. Operator skill/ease of use. Plume containment and remediation.
b. Could allow for less operator training.
7)a. Easier operation.

b. If something is designed for the field, a child should be able to operate it.

8)a. Less expensive monitoring. Cheaper equipment would be good for all areas (plume, landfill, tank, haz. waste). For example, in aquifer pump testing, the present equipment is expensive to rent and not reliable.

b. Expensive and not reliable (no brands come to mind)

9)a. Decreased secondary waste generation. Hazardous waste characterization.

b. All seem to produce waste. Present equipment makes it harder to do investigative work and remediation.

10)a. Improved operator safety. All areas.

b. Well, yeah. Its self-explanatory. A person holding it (instrument) should be safe.

11)a. Improved sensing of contaminants in water. Plume containment and hazardous waste.

b. Present equipment has limited range and often detects only a single contaminant.

12)a. Improved sensing of contaminants in water. Ground water analysis.

b. There is no immediate sense of the contaminants in a well. Field screening methods provide parts per million which is not as good as what lab analysis can provide. Would like to see field instruments that can provide a better range.

13)a. Improved temperature range operations. Plume containment.

b. Some field instruments are not built for actual field conditions.

14)a. Decreased secondary waste generation. All.

b. It (secondary waste generation) costs money (to dispose).

15)a. Increased resolution. Metals in soils/solids.

b. Respondant would like to see lower detection limits for XRF surface soil detection of metals.

16)a. Real-time sensing. In any areas (hazardous waste, waste tank, etc.) where it would expedite site analysis and get work done in one short swoop.

b. No validity to the answers. How much can you trust the results compared to lab?

17)a. Improved regulator acceptance. All areas, expecially USTs.

b. Regulator acceptance is very important.

18)a. Improved subsurface soil sensing. Primarily groundwater work.

b. Delineation and resolution, again, are not very good.

19)a. Improved operator safety. In general.

b. When charging some units, you have to handle flammable gas so you must be careful with that.

Q14. a. (The third of the 3-5 top needs) For ____, in which area of your work do you most need this feature?

b. What are the inadequacies of the current equipment in this respect?

2)a. Extended sensor life.
b. Overall instrumentation performance.
3)a. Improved sensing of contaminants in soil.
b. It would reduce costs and time.
4)a. Easier operation. Air monitoring.
b. Much of it is too bulky and large, and the software is too complicated.
6)a. Regulator acceptance. Plume containment and remediation.
b. Regulators are too slow in accepting equipment.
7)a. Regulator acceptance.
b. If it is not accepted by regulators, it can not be used.
8)a. Easier operation. In all areas, technicians have to go out frequently to monitor, especially water levels.
b. Instructions are not easy to sit down and read. Technicians have to be trained. User guides are badly written. When manuals get misplaced, it is not obvious what dials mean.
9)a. Integrity verification. Hazardous waste characterization.
b. Integrity is not good enough, making it harder to analyze contaminants. If the integrity is not there, it is hard to get regulatory agencies to buy off on the results. It makes it hard to build a usable and defensible case.
10) Integrity verification. All areas
11)a. Improved temperature range operation. (Especially in Montana). Plume containment and hazardous waste.
b. Equipment is not durable under a wide range of temperature conditions.
12)a. Improved sensing of contaminants in sludge. Abandoned mines.
b. Results from field analysis don't correlate well with labs. Matter of sensitivity. Field results often depend on soil type and other factors.
13)a. Smaller/ more lightweight. Plume containment.
b. A lot of equipment is heavy to lug around for people who spend a lot of time in the field.
14) Improved operator safety. All.
15)a. Regulator acceptance. All.
b. Before you use equipment, you would like to have the results acceptable in a final report without excessive laboratory confirmation.
16)a. Easier operation. Mostly hazardous waste work.
b. It would be nice to have fewer switches and more internal calibration. Maybe just fewer buttons overall.
17)a. Improved sensing of contaminants in water. Water area.

b. Resolution is poor.
19)a. Easier operation. All.
b. A lot of the equipment that they have is difficult to calibrate, especially if you do not have the manual handy. It would be nice if you able to plug it in, push a few buttons, and be ready to go.

Q15. a. (The fourth of the 3-5 top needs) For ____, in which area of your work do you most need this feature?
b. What are the inadequacies of the current equipment in this respect?

7)a. Integrity verification. (All areas)
b. You want to know that the thing does what it says it does.
14) Improved regulator acceptance. All.
15) Improved detection of metals. Soil characterization.
b. Respondant would like to see lower detection limits for XRF surface soil detection of metals.
16)a. Improved resistance to moisture. Hazardous waste and waste tank work.
b. Microtip has gotten better. Need improved PIDs.
19)a. Improved resistance to moisture. USTs, all.
b. Resistance to moisture is very big because in areas such as well heads you have very high humidity, and in wells and soil samples moisture will give you false readings.

Q16. a. (The fifth of the 3-5 top needs) For ____, in which area of your work do you most need this feature?
b. What are the inadequacies of the current equipment in this respect?

15) Real-time monitoring. All.
b. Well, its given really that a field instrument will give you real-time results.

Q17. Do you have any other comments regarding the current state of field deployable sensors?

1) Not really
2) No.
3) No.
4) That is the direction to move toward (site analysis opposed to sample/lab work). Much work is going on there now and there is no need to go to the lab. Very important area.
5) Would like more accuracy and instruments that are smaller and more portable.

6) No.
7) No, I don't.
8) The equipment has been improving quickly.
9) Would like to see equipment for the field analysis of more metals.
10) Nope.
11) No
12) The equipment is still pretty expensive.
13) It would be nice if instruments had a longer battery life.
14) Not really.
15) Nothing I can think of.
16) Need standardized equipment. Better calibration of gases and solutions in lamps, probes, etc. Consistency is needed between manufacturers and products.
17) No, not really.
18) Nothing.
19) No.
20) Not off of the top of my head. I would have to reflect on it.

Survey Results - Environmental Process Monitoring Interviews

Interviews are coded with a number from 1b to 14b. For each interview, the location of the company, title of individual interviewed, and remediation process are listed. To ensure the anonymity of the participants, the names of interviewees and their companies have been removed.

Nearly all of the interviews were with main or branch offices of environmental engineering or environmental consulting firms. Particular remediation processes of interest, such as in-situ vitrification and soil washing were targeted, yielding a less than random sample. These firms contacted ranged from 8 to 100 employees at the location, typically 20-40. Most of the interviewees work with a variety of industries on a number of projects at any given time, with a few specializing in government or a single industry. Most of the participants specialized in a single remediation process.

The location of the establishment contacted and the title of the interviewee are listed below, coded from 1b to 14b. These numbers are used to identify responses from the interviewees throughout this summary.

1b. Florida
President
Soil washing.

2b. Wisconsin
Senior Process Engineer
Groundwater remediation-biological/granulated carbon adsorption.

3b. Washington state
Senior Project Engineer, Business Development.
In-situ vitrification.

4b. Illinois
President
Catalytic incineration.

5b. New York
Environmental Monitoring Manager
Landfills.

6b. Texas
Vice President
Ground water remediation.

7b. Illinois
Senior Environmental Engineer

Landfill closure.

8b. Montana
Project Manager / Staff Engineer
Decontamination / demolition.

9b. Texas
Vice President of Technology Development
Soil washing.

10b. Iowa
Technical Sales Representative
Ground water remediation.

Interviews 11b-14b were with companies which were identified as remediation process suppliers but either exited the business or did not use field instruments. These brief interview findings are included for completeness.

11b. Minnesota
Used IA kit for soil washing demonstration project.

12b. Alabama
Did not use field analysis for soil washing process.

13b. Georgia
Used samples rather than field instruments due to the lack of sensitivity of field instruments on past soil washing project.

14b. Georgia
Used a field GC for characterization and health monitoring, but no instruments for monitoring the process at a soil washing test site.

For the remediation process monitoring interviews, the respondants were asked if they performed each type of service in questions 1 to 5. If the service was supplied, the method of analysis and field instruments use were asked next. The responses are summarized in the table below.

PROCESS	a. % OF TIME	b. SAMPLES OR FIELD MON.	c. FIELD INSTRUMENTS USED PORTABLE/ INSTALLED FEATURES
Q1.Barrier Integrity	5b) 100%	Samples	Field measure pH, conductivity, temperature, turbidity, but not VOCs, SVOCs, etc.
	7b) 5%	Both	Have used some screening instruments. BOBA comes to mind.
Q2.In-Situ Vitrification	3b) 100%	Samples	Air grab samples - off gases. It depends on the regulations. Also sample products. TCLP (Toxic Characteristic Leaching Procedure) for metals. At the high temperatures they operate at, it is physically impossible for organics to exist, they are completely destroyed. They analyze the waste for metals, but it is too hot to analyze the process as they melt the soil at 1,600 to 2,000°C.
Q3.Soil Washing	1b) 100%	samples to on-site lab	Analyze excavation area, the feed into the process, and the products out of the process. They take samples, and analyze them in an on-site lab, so they batch analyze, but in a continuous process. Field lab
	9b) 100%	Both	HNU Gas Chromatograph. Immunoassay tests to measure pH - Ohmicron. Is purchasing an X-Ray Fluorescence (XRF) to measure chromium and arsenic. They use a geiger counter to measure radioactivity.
PROCESS	a. % OF TIME	b. SAMPLES OR FIELD MON.	c. FIELD INSTRUMENTS USED PORTABLE/ INSTALLED FEATURES
Q4.Ground Water Cleaning - effluent	6b) less than 1%	Both	For explosive detection, they use D-tect (Immunoassay) for locating TNT and RDX. For reactives, they use samples. In their treatment process, instrumentation is permanently mounted in a field trailer to measure effluent (input into a liquid-phase reactor) pH, conductivity, temperature and turbidity.

Q5.VOC destruction	4b) 100%	None	They only monitor temperature for there process. CEMs (continuous emissions monitors) are not required for catalytic incineration. They only need to monitor the temperature above and below the catalyst bed. Who ever is operating the equipment (them, a customer, or contractor) does the monitoring. They install sensors that record data on a strip chart, or computer interface, whatever the final user wants.
Q6.Facility Decom. & Decon.	8b) 10%	Both	Maybe specific pollutant monitors in air such as H2S or CO2. Includes ambient air monitors such as an MSA on the belt, or Drager or Sensidyne tubes for samples sent to the lab. If you are concerned about VOCs, you might use a photoionization detector or a FID or something like that. XRFs are pricey. Have used IA test kits.

3b) The respondent did not use field instruments at all, but took samples.

4b) Since they did not use instruments included in the study, the interview was terminated.

5b) Interviewee oversees all monitoring of closed and operating landfills for the (landfill company). They have no open hazardous waste landfills as they are out of the hazardous waste business, but they monitor 5 closed hazardous landfills, and other sanitary landfills which are closed and several which are operating. They hire outside companies to collect samples. They collect groundwater samples from 300 monitoring wells, for example site Secure 5 has 50 wells for groundwater, and 4 leachate sample points taken semi-annually under the New York state 373 permitting program. The samples are sent to New York certified labs. They use field instruments for pH, conductivity, temperature, turbidity, but those are the only field parameters. Measurement for VOCs and SVOCs are outside of the realm of required parameters. They do not use field GCs or that sort of thing. He is not sure if the reason they do sampling is because regulators do not accept field measurements, or if it is cost, but he suspects that to set up a portable lab for 4 or 5 days a month would cost much more than to send samples to a full-time lab. Time savings do not exist for them, as the lab is nearby and the results are not urgent. He doesn't know if New York state accepts field lab results or field results for chemicals. Since no field instruments were used, the interview was terminated.

8b) Decontamination and Demolition is not their main business, but a secondary side-line. They are mainly environmental construction, earth moving or RCRA cells with an environmental angle.

Secondarily they do sludge pond desication - clean up - and demolition/ decontamination/ closure. He has spent about 10% of his time over 5 years in D&D. A fourth area in which he is involved is soil remediation such as air sparging. A situation where they did not demolish, but only did decontamination was a local plating facility. They needed to go below the floor, angle drill, and analyze what was under there, make a determination so they could clean, and the state could close the site for the property owner. For the most part they field screen if appropriate. PID or FID for VOCs. MSA monitor on the belt for other contaminants in air for worker exposure. Drager or Sensidyne tubes also give real-time measurements. Mostly they use grab samples before they mobilize to the site. When they are confident they will not have exposure, they use a NIOSH/OSHA approved pump on the belt which takes 3 samples/day. It is strange but they just verify that they did not expose the workers. Those detection limits are defined more strongly than calorimetric tubes. They are tame, have not gotten into more exotic compound measurement in real time. XRF is pricey, it requires a lot of QA (Quality Assurance) to verify the results.

Q7. a. Do you expect your company to purchase process monitoring instrumentation in the next 12 months?
b. For what reason(s)?
c. How much do you plan to spend?

1b) No. It is set.
2b)a. Yes.
b. New installations. Not only GAC fluid bed but in their full range of equipment.
c. Can't say.
6b) No.
7b) No.
8b)a. Yes.
b. Replacement or upgrade. Possibly also growth in the business.
c. I could not tell you. Someone privy to the budget could say, but you would need to do some hard talking to get them to tell you.
9b)a. Yes.
b. For a big project.
c. Less than $50,000 for an XRF.
10b)a. Yes.
b. Replace an immunoassay kit in which there is no confidence. Quantex was the company.
c. Less than $50,000.

Q8. a. Are there occasions where you would have liked to monitor a process in the field, but were required to send samples to the lab?

b. Why were you unable to monitor in the field?
c. If equipment were available that overcame the limitation(s), would you purchase it?

1b) No, not really. It is easy to do it the way they do now, and on-line process measurement won't help much in our process.
2b) No.
6b) No. The process can be studied in the field, but it has to be verified in the lab to avoid litigation.
7b) No.
8b)a. Hell yes. I could not say that more strongly.
b. We are a lean company. Unless you are in a gravy train field, you have to struggle. In certain cases one unit which we own and is seldom used might be used by someone else when you need it. There are other situations. Basically limited resources within our company.
c. You have to cost justify equipment purchases. Equipment is bought when needed, but not a million dollar piece of equipment unless it is cost justified, which would be unusual.
9b) No. Lab turnaround has been good. Their next project, however, may require a 3-day turnaround which is not so good. They will bring on-site some equipment to measure pH, chromium and arsenic (XRF) and a GC.
10b)a. Yes
b. Cost prohibitive. Would like to measure pH and oxygen levels in wells and download results.
c. Yes.

Q9. I would like to go through a list of potential characteristics of environmental field analytic instruments, and I would like you to rate each one on a scale from 1 to 5 where 1 is not important, 2 is somewhat important, 3 is average importance, 4 is very important, and 5 is urgently important. Keep in mind that the next set of questions is not about what equipment you currently use, but about what equipment you would like to see brought to market.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *	Other
a. Improved data collection capacity/freq.	✔✔		✔✔✔✔	✔			
b. Real-time sensing		✔	✔✔✔	✔	✔✔	**	
c. Continuous monitoring	✔	✔	✔✔✔✔✔				
d. Less expensive monitoring		✔	✔	✔	✔✔✔	****	4.5
e. Rugged construction		✔	✔	✔	✔✔✔✔	**** *	
f. Increased resolution		✔✔	✔✔	✔✔✔			
g. Remote operation	✔	✔		✔✔✔✔			0
h. Ease of installation		✔✔	✔✔	✔✔✔			
i. Improved regulator acceptance		✔		✔✔	✔✔✔✔	****	
j. Reduced maintenance (consumables/calibration)		✔		✔✔✔✔✔	✔		
k. Smaller/ more lightweight	✔✔	✔	✔	✔✔✔			
l. Integrity verification		✔✔	✔	✔✔✔			3.5
m.Improved temperature range operation		✔✔	✔✔	✔✔	✔	*	
n. Improved resistance to moisture			✔✔	✔✔	✔✔	*	n/a
o. Improved sensing of contaminants in air		✔	✔✔	✔	✔✔	*	n/a
p. Improved sensing of cont. in water		✔	✔✔	✔✔✔			3.5
q. Improved sensing of cont. in sludge	✔	✔	✔✔	✔✔			n/a
r. Improved sensing of contaminants in soil			✔	✔✔✔✔	✔		n/a
s. Improved subsurface soil sensing	✔			✔✔✔			n/a, n/a.
t. Improved sensing of contaminants in concrete/ metal pipes/ other solid materials	✔✔ ✔		✔	✔			n/a, 3.5
u. Extended sensor life		✔✔	✔✔	✔✔	✔	*	
v. Improved Detection of radioactive contaminants	✔	✔		✔✔✔		*	n/a.

Top 3-5 is checked for the number of times which the feature was mentioned as the top 3 to 5 most desirable features in Questions 11-16.

Other responses include not applicable or no opinion. When a multiple answer was given such as "3 or 4", the mean was entered, "3.5" in this case.

If 4 or 5: *to v:* Which radioactive contaminants?(Transuranics (TRU)-Cesium-137 & Strontium -90, Plutonium , Uranium, Other)

1b) Whatever you run into. The 20 key radioactive contaminants, Uranium, Cesium, Strontium, Cobalt, etc., I forget exactly what they are. No necessarily alpha but by contaminant.
7b) Haven't worked in the mixed waste area in several years.
9b) Uranium and Radium. Have not dealt with others.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
w. Improved detection of metals	✔✔		✔✔✔	✔✔		

If 4 or 5: *to w:* Which metals? Mercury, Lead, (Hexavalent) Chromium, Arsenic, Nickel, Cadmium?

1b) All of them
9b) Mercury, Lead, Chromium, Arsenic, and Cadmium.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
x. Improved detection of organics			✔✔✔✔✔	✔✔		

If 4 or 5: *to x:* Which organics?

	Yes
Polychlorinated Biphenyls (PCBs) -	
TCE -	
TCA -	
Perc -	
Freon-133 -	
Carbon Tetrachloride -	
Chloroform -	
Toluene -	✔
Benzene -	✔

2b) BTEX (benzene, toluene, ethyl benzene, xylene)
8b) Personally, I work with petroleum hydrocarbons, BTEX, pema, chlorpenathol, dioxin a little. TCE, TCA, DCE - those compounds.

	1 Not Import	2 Some Import	3 Av. Import	4 Very Import	5 Urgent Import	Top 3-5 *
y. Improved detection of other pollutants	✔✔	✔	✔✔ ✔	✔		

If 4 or 5: to y: Which other pollutants?

Which other pollutants?	Yes
Nitrates -	✔
Cyanide -	✔
Ferrocyanide -	✔
Phosphorus -	✔
Sulfur -	✔
Noble metals -	
Dense Non-Aqueous Phase Liquids -	

2b) diesel organic fractions
6b) explosives outside of the nitrate family

Q10. Can you think of others ideal product features I have not mentioned?

1b) No.
2b) No.
6b) Ease of operation
7b) No.
8b) No.
9b) No.
10b) No.

Q11. Of all of the characteristics, could you select 3 to 5 which are the most important or most urgent but are not commercially available in existing equipment?

1b) Detection of radioactive contaminants. Detection of metals.
2b) Less expensive. Rugged construction. Improved acceptance.
6b) Real-time sensing. Less expensive monitoring. Rugged construction.
7b) Improved regulator acceptance. Improved resistance to moisture. Improved sensing of contaminants in air. Extended sensor life.
8b) Real-time sensing. Rugged construction. Improved temperature range operation. Others are implied by that. Rugged implies reduced maintenance.

9b) Improved regulator acceptance. Less expensive monitoring. Rugged construction.

10b) Less expensive. Rugged construction. Improved regulator acceptance.

Q12. a. (The first of the 3-5 top needs) For ____, in which area of your work do you most need this feature?

b. What are the inadequacies of the current equipment in this respect? What improvements are desired?

1b) Only worked in soil washing. Yes, there are inadequacies, but that is a big subject. Why are they inadequate? Sample collection, sample preparation, contacting, everything is not adequate.

2b) Only worked in ground water remediation. Less expensive monitoring. It is always important. They are always looking to reduce costs. Cost is of prime importance to an OEM in a competitive marketplace.

6b) Real-time sensing. Area of military chemical weapons. Not just soil flushing (a ground water treatment technology), but for anything, including off-gas detection. Have to use "near" real-time sensing - equipment that takes 12 minutes. By that time, people could be dead and dying.

7b) Improved regulator acceptance. For RCRA work. They don't accept soil gas results unless a sample in analyzed in the lab.

8b) Real-time sensing. All areas. It is almost a given.

9b) Improved regulator acceptance. Soil washing. Certain tests are not accepted. For example, immunoassays are accepted in some states and not others.

10b) Less expensive monitoring. Field work with ground water and wells.Testing for BTEX or immunoassay can get pretty expensive. If the costs were less, it would be viable to run tests in the field. If the test results are only within 20%, why spend the money to get that close - just send samples back to the lab.

Q13. a. (The second of the 3-5 top needs) For ____, in which area of your work do you most need this feature?

b. What are the inadequacies of the current equipment in this respect? What improvements are desired?

1b) Only worked in soil washing. Detection of metals. That is pretty broad.

2b) Only worked in ground water remediation. Rugged/reliability are importance. Without the equipment, there are no alternatives.

6b) Less expensive monitoring. Area of military chemical weapons. Not just soil flushing (a ground water treatment technology), but for anything, including off-gas detection. Equipment is sophisticated, very expensive, and inadequate.
7b) Improved resistance to moisture. For RCRA work. Harder to get accurate results when it is raining or there are high moisture conditions.
8b) Temperature range is critical up here (Montana). All areas. The other day it was 29 below and today it is in the 60s.
9b) Less expensive monitoring. Soil washing work. They will purchase XRF equipment. They are not very familiar with it, but like so many instruments, it will be fairly expensive, up to $50,000.
10b) Rugged construction. Field work with ground water and wells. No matter how careful you are, sometimes the equipment is going to take a hit. It would be good if it were not so fragile.

Q14. a. (The third of the 3-5 top needs) For ____, in which area of your work do you most need this feature?
b. What are the inadequacies of the current equipment in this respect? What improvements are desired?

1b) Only worked in soil washing. Improved detection of organics. Also very broad.
2b) Only worked in ground water remediation. Regulator acceptance. Monitoring is not necessary for the operation of the equipment. It depends on the permits. If continuous monitoring is needed for regulatory concerns then it is used. Permitting is really the key, permitting drives regulatory oversight which drives the use of monitors.
6b) Rugged construction. Area of military chemical weapons. Not just soil flushing (a ground water treatment technology), but for anything, including off-gas detection. Equipment is bulky and too sensitive. It also is extremely difficult to calibrate and keep running.
7b) Improved sensing of contaminants in air. Health and safety monitoring for personnel. Action levels vary too much and you have to ask yourself, "What is it actually measuring?"
8b) Rugged construction (and reduced maintenance). All areas. With the bozos around here, they are lucky that they do not back over the equipment on their way home.
9b) Rugged construction. Soil washing work. Some equipment won't stand up to being hauled from site to site. They have had trouble with HNU's.
10b) Improved regulator acceptance. Field work with ground water and wells. Bioremediation technology is sometimes not

accepted by regulators. It is hard to introduce in some places were regulators are not familiar with it. Results from lab work build confidence levels.

Q15. a. (The fourth of the 3-5 top needs) For ____, in which area of your work do you most need this feature?

b. What are the inadequacies of the current equipment in this respect? What improvements are desired?

7b) Extended sensor life. No particular area. Just never sure when you're going to break through and lose the filter fuse.

Q16. There were no cases where a respondant had identified five top needs.

Q17. Do you have any other comments?

2b) No. They are generally unreliable, but you always have backups.

Current Environmental Analysis Methods

The primary method for environmental analysis was found to be field sampling and laboratory analysis. Field analysis was often viewed as only a secondary, supplemental method in support of field sampling. In fact, a situation where field analysis only was performed without any laboratory analysis was not encountered in the course of our interviews. Even in cases where field instruments are used extensively, a minimum of 10% of samples are sent to a laboratory for verification and backup of results. In most cases, sampling was the only method use to characterize a site, characterize waste encountered at a site, and even to monitor a remediation process.

The primary reason for the widespread use of field sampling and laboratory analysis is to ensure the collection of regulator accepted data. In most cases, regulators lack confidence in field measurements. In cases where a very large volume of highly reliable measurements are required, a field laboratory may be cost justifiable.

Environmental Testing Laboratories

As environmental testing laboratories are a significant substitute to field analysis, and the current preferred methodology, it is appropriate to briefly consider the market for environmental laboratory analysis.

A surge in environmental services in the 1980s precipitated a buildup of environmental testing laboratory capacity. This was aided by Safe Drinking Water Act and Clean Water Act requirements for more extensive testing of municipal water treatment facilities. In the 1990s there was a decline in demand, and consolidation in the laboratory industry. Decreased demand, as well as the introduction of some inexpensive field methods such as Immunoassay tests have forced labs to decrease costs. Despite this slowdown in growth, revenue to environmental testing laboratories exceeded $1.6 billion in 1995[1]. The average annual growth for laboratory-based environmental analytical testing services is expected to be under 4% for the next five years[2].

Many larger environmental consulting companies and industrial companies, such as those in the petrochemicals industry, maintain internal environmental laboratories. While this market is relatively small compared to independent laboratories, so called captive laboratories amount to approximately $150 million of sample processing.[3]

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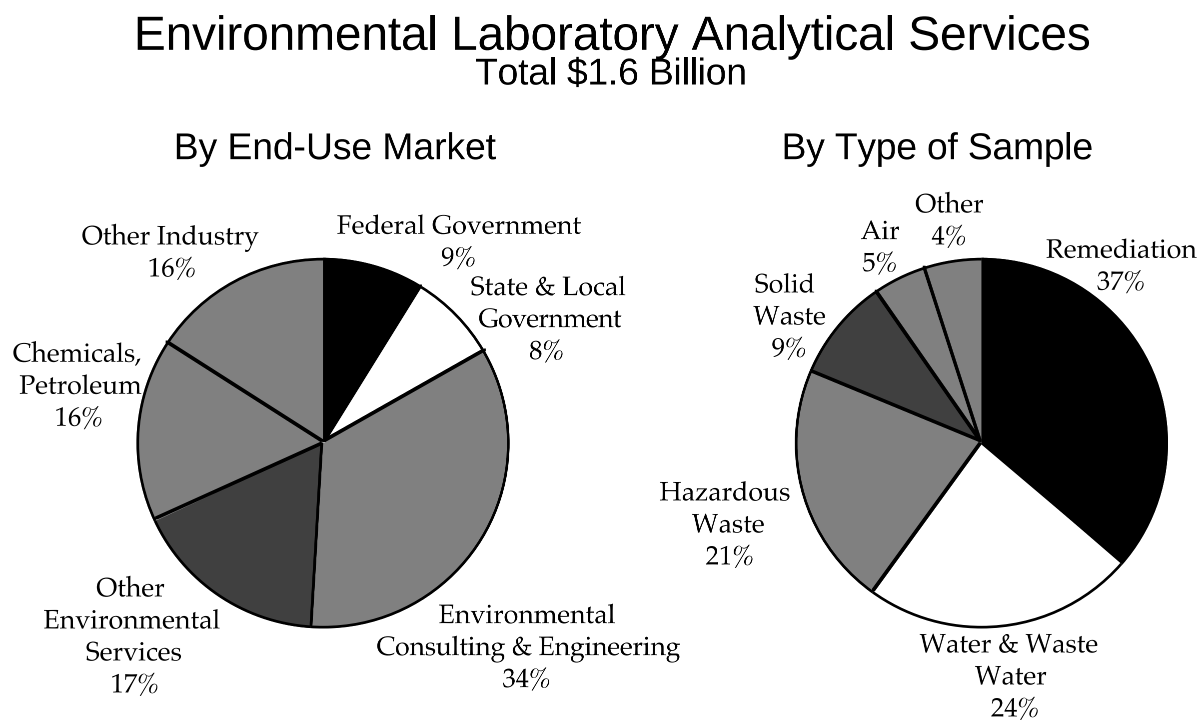
[1] TechKNOWLEDGEy Strategic Group, Boulder Colorado.
[2] TechKNOWLEDGEy Strategic Group.
[3] Unimar estimates.

All told, there are approximately 1,600 environmental analytical testing labs in the U. S.[1] The top 30 firms account for 46% of the market with 1,300 smaller firms making up 47% of the market, and captive laboratories accounting for the remaining 7% of the market.[2]

The users of environmental testing and analytical services are also large purchasers of environmental field equipment. Over half, 51%, of environmental laboratory services are purchased by environmental firms such as environmental consulting and engineering firms, hazardous waste management firms, and others. Private industry comprises 32% of the market and encompasses a wide range of users such as petroleum retailing, petroleum refining, chemicals manufacturing, utilities, mining, agriculture, and many other industries. Government comprises 17% of these services, evenly divided between federal users (9%) such as the DOD, DOE, and EPA and state and local government (8%) users such as municipal water works, publicly owned treatment works, and regulatory agencies. This market breakdown, as well as the distribution of the types of samples analyzed by labs is shown in the figures below.[3]



Source: TechKNOWLEDGEy Strategic Group Boulder, Colorado.

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[1] Organisation for Economic Co-operation and Development. The OECD Environment Industry: Situation, Prospects and Government Policies. Paris: The OECD, 1992. p. 3-11.

[2] OECD, p. 3-12.

[3] Jones, Landon. "Lab Bad News May Be Good For Others", Waste Tech News, January 30, 1995. p.1-3.

The reduction of direct and indirect costs of sample laboratory analysis drives the slow movement of analysis out of the laboratory and into the field. Laboratory fees are a sore point among many environmental services companies. Even with prices falling as a result of overcapacity and field methods, many users feel they are at the mercy of the laboratory. This large direct expense is often conspicuous as an area of potential for cost reduction. A second direct expense associated with laboratory analysis is the cost of collecting, labeling, and transporting samples to the lab. The direct cost of sample gathering and tracking may be two to three times the cost of processing the sample, depending on the location of the sample and the areas geology. Finally, the largest cost associated with laboratory analysis is the indirect cost of time. In some cases, time may not be a consideration, but in many remediation projects, time may be extremely expensive, such as when a contractor must be idled pending the results of off-site laboratory analysis. These direct and indirect cost and efficiency disadvantages of laboratory analysis drive the development of improved field characterization methods.

Environmental Field Laboratories

Occasionally, a field laboratory is deployed on-site for site characterization or waste characterization. In cases where a large volume of samples require analysis with a one to two day turnaround, a dedicated trailer-mounted laboratory complete with laboratory equipment and laboratory personnel may be mobilized on-site. While the cases in which a field lab are considered to be cost justified is on the rise, a field lab is still the exception. The number of field labs currently mobilized in the U. S. is estimated to be under 100.[1] Nevertheless, field laboratories are an important step in the evolution of on-site environmental analysis.

While field laboratories are emerging as a tool for site characterization, they are still extremely rare for examination of samples taken from a remediation process. While the volume of analysis in extensive site characterization may justify dedicated analysis equipment on-site, samples from remediation processes are analyzed at the minimum level required by regulations. Often, this means one or two samples analyzed off-site per year, which will not justify having dedicated laboratory equipment in the field.

With the rise of the field lab for site characterization, a case may be made that laboratory equipment which can be transported to the field may be considered field equipment. This is not the case for the purposes of this study, as the amount of equipment in field laboratories is only a very small portion of all

[1] Dionex and other estimates.

laboratory equipment, and of all field equipment. In order to be considered as field equipment for our purposes, the device must have been specifically designed for field use.

Environmental Field Instrumentation

The December 1995 issue of the Environmental Business Journal notes a trend of environmental analysis moving out of the lab and into the field.[1] This observation is misleading, because field analysis remains a niched supplement to laboratory analysis, and is not likely to replace laboratory analysis entirely. While laboratory instrument sales have fallen from 62% of environmental instrument sales in 1993 to 56% in 1995, field instruments still only account for 8% of environmental instrument sales.[2] The remaining 36% of instrument sales consists of environmental industrial process monitoring, emission monitoring, and other areas. The drop in laboratory equipment's share of sales can be attributed both to slowing of sales in a consolidating laboratory market, and increasing sales of field instruments and industrial process monitoring systems. Field instruments currently do not approach the quality of laboratory analysis. It would be more accurate to state that field analysis is slowly growing to join laboratory analysis as a significant tool for the environmental engineer.

Field instruments occupy a number of niched applications for environmental analysis. With improvements in ruggedness, operational range, and contaminants detected, sales of field instruments have been rising at an annual rate of around 6%[3] to approximately $140 million.[4] Instruments are used in the field to direct a site characterization, reduce the number of samples required, increase the efficiency of the samples which are taken, monitor the safety of workers on-site, and monitor remediation processes, among other purposes. Inexpensive field instruments and occasionally field labs can be used to target the sampling plan to reduce the number of samples by as much as 90%. Commonly used field instruments include Gas Chromatographs, Photoionization Detectors, Flame Ionization Detectors, X-Ray Fluorescence, and Immunoassay kits. Of these, the emerging low cost Immunoassay kits are seen as the most significant threat by the laboratory-based environmental testing industry.

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[1] "Environmental Instrumentation on Global Course". Environmental Business Journal. December, 1995. p. 1-3.

[2] "Environmental Instrumentation on Global Course" places the value of non-laboratory instruments at 44% of total environmental instrument sales. Further modeling and estimates place the value of field instruments as defined in the study to be approximately 8% of the total. This 8% for field instruments falls within the 44% of sales outside of the laboratory.

[3] "Environmental Instrumentation on Global Course" and other data.

[4] This value is derived later in this section.

Industrial Process Monitoring

Another much larger market which somewhat overlaps with environmental field instrumentation is industrial process monitoring. Many industrial processes including chemicals manufacturing, municipal water and waste water treatment, industrial water and waste water treatment use instrumentation to monitor pH, conductivity, temperature, turbidity, total oxygen, and various chemical concentrations. A number of instruments are used for purposes such as leak detection of liquid and gaseous piping, and general fugitive air emissions.

The size of the market for industrial process monitoring depends on how the market is defined. If industrial process monitoring is considered to include sensors, system design, wiring, and labor, the total market for industrial process monitoring instrumentation in 1995 was over $6 billion.[1] Approximately 10% of this total,[2] or $600 million, is for industrial process monitoring which is considered to be for "environmental" purposes. This is usually monitoring a process for leaks into the atmosphere or environment. Under 2% of this instrumentation falls within the scope of this project by being used at environmental remediation sites. This amounts to approximately $12 million, with some field instruments finding dual use for site characterization and ambient air monitoring. As in other areas of field instruments, an unrealized potential exists for replacing the dominant technology of laboratory analysis with increased field monitoring of environmental remediation processes.

Field Instrumentation

Field instruments occupy a number of niched applications for environmental analysis. Overall, the use of field instrumentation is increasing at an annual rate of around 8%,[3] but the full potential of field instrumentation has not been approached. The market for field instrumentation has been described by vendors as a fractured developing market. Vendors are supplying equipment which is being purchased and used successfully in the field, but the technology has limitations compared to the alternative of laboratory analysis.

Before we examine the technologies used in the field, it is helpful to understand what technologies are considered to be field instruments, and what barriers exist to instrument sales.

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[1] United Stated Department of Commerce, Bureau of the Census. Current Industrial Reports: Selected Instruments and Related Products. Washington, DC: U. S. Department of Commerce, November, 1995.
[2]Vendor consensus.
[3] "Environmental Instrumentation on Global Course".

Scope

As previously mentioned, field instrumentation may have a broad interpretation. In the course of our study, laboratory equipment transported to the field was not considered to be field equipment. We are only considering equipment which has been specifically designed for the field. Field instruments for measuring radiation and Continuous Emissions Monitors (CEMs) were considered outside of the scope of this project, as they may be the subject of future studies. Field devices which detect radionuclides in all media and instruments which detect compounds in air are included in this study.

Market Barriers

Each of the instruments encountered has had to address several obstacles before entering the marketplace – technical development, reliability, and cost. These barriers must also be addressed by any new technology which shows promise.

An assumption regarding any instrument technology is that is has been shown to be technically sound prior to being brought to the marketplace. It has been estimated that technology development requires from 3 to 5 years, and that little can be done to accelerate this process. Fortunately for many of the market needs presented later, the state of research for sensing and analytical methods is strong. Promising technologies, however, must be proven to be reliable in the field over time.

It goes without saying that high equipment reliability is a minimum requirement for market acceptance. Most currently available field instrumentation is considered minimally reliable by users and regulators. Several of the interview participants stated that equipment which made highly reliable measurements in the field, such as field laboratory equipment is prohibitively expensive compared to alternatives. Current inexpensive field instruments are not sufficiently reliable for complete analysis. Even after a technique is proven reliable, a lengthy period exists before new procedures become accepted practice.

In cases where field instrumentation is available at an acceptable cost, it still may not be acceptable to regulators. The user will not realize cost savings if field measurements must be supplemented with full laboratory analysis for regulatory purposes. Fortunately, once-proscriptive regulators are attempting to become more performance-based when it comes to field instrumentation.[1] Field characterization plans with as much as 20% field analysis are common

[1] United Stated Environmental Protection Agency, Region 5, Chicago, Illinois.

and plans with 80% field analysis have been approved. While the transition to field analysis wherever possible has been established as a policy goal, the progress toward performance-based standards has been admittedly slow. One reason cited for this slow growth is the reluctance of land-owners to accept the risk of using newer methods for their individual projects.[1]

During the course of the Workshop on Chemical Sensors for Environmental Applications, interesting evidence of how important regulations were as a market driver was discovered. A "chicken and egg" relationship was observed between the regulation of a situation[2] and the development of instrumentation. It seems that regulation will not be possible until instrumentation is developed to detect a particular circumstance. It also seems that instrumentation will not be developed until the situation is regulated. Despite this stand-off, it is obvious that from a market perspective, the developer of this technology would face a large market potential.

The other primary market driver is cost of both money and time. An underlying assumption of this study is that field characterization and field monitoring would be less expensive and quicker than laboratory analysis. In most cases this is true, particularly when a large number of samples are required, or where time delays are directly tied to raising costs, such as when a contractor must be idled while laboratory results are pending. In other cases, even the most accurate, inexpensive field instrument could be more troublesome than sending a few, routine record-keeping samples for laboratory analysis. Small companies do not wish to make any investment in time to develop in-house expertise for minor processes when the inexpensive outsourcing is available.

Essentially, there are three criteria for development of field instrumentation for environmental analysis:

- The challenge of developing superior technology;
- Gaining regulatory confidence of accuracy and reliability;
- Developing commercial technology at an acceptable cost relative to current practices.

These latter two criteria must not be overlooked when considering the development of instrumentation. In our survey, nine respondents were unable to perform characterization in the field. Six times the reason cited was the cost of equipment and six times the reason given was lack of regulator acceptance (allowing for multiple responses). Technical qualifications are not

[1] Participant at the Workshop on Chemical Sensors for Environmental Applications sponsered by the Characterization, Monitoring, and Sensing Technology Crosscutting Program (CMST-CP) in Chicago, Illinois, March 1-2, 1996.
[2]The regulation of metals in stack emissions.

sufficient for equipment acceptance in this area, as formidable cost and regulatory acceptance hurdles must be cleared by even a hypothetically perfect instrument.

Field instrument usage will increase when equipment is more consistently accurate, reliable, easier to use, and lower cost.

A number of different field instruments have been developed that have begun to overcome these barriers and are commonly in use. Among these are Gas Chromatographs/ Mass Spectrometers, Photoionization Detectors, and Flame Ionization Detectors. Other instruments achieving acceptance are X-Ray Fluorescence analyzers and Immunoassay kits. Other commercially available technologies which were not directly encountered in the course of the interviews include fiber optic sensors, infrared sensors, piezoelectric sensors, and electrochemical sensors. The market position of each of these technologies is briefly described below.

Gas Chromatographs/ Mass Spectrometers

Gas Chromatography is a large field, and can be considered a sub-field of detectors in general. The Gas Chromatograph (GC) is a standard instrument found in many laboratories, with sales of gas chromatographs over $400 million in 1993 in the U. S.[1] Field GCs are less widespread, with U. S. sales of around $52 million in 1996.[2] GCs may be used alone, with various detectors such as flame ionization detector, thermionic emission detector, photoionization detector, and others, or with a mass spectrometer.

Field GCs are popular due to their versatility in identifying organic compounds in air, water, or soil samples. Product features such as size, resolution, and capabilities vary with different equipment and different sensors, but in general, GCs are effective at analyzing volatile organic compounds (VOCs), polychlorinated biphenols (PCBs), polyaromatic hydrocarbons (PAHs) in air such as soil gas emissions, water samples, ground water samples, and soil samples. Other contaminants detectable with GCs include semi-volatile organic compounds (SVOCs), certain pesticides, and toxics. An advantage of GCs is that they are capable of identifying multiple compounds in a single sample. Some field GCs can identify up to 25 separate contaminants.

[1] United States Department of Commerce. Current Industrial Reports: Selected Instruments and Related Products.
[2] Derived later in this chapter.

GCs can range in price from as low as $7,000 to as high as $50,000.[1] A typical system for field use can range from $20,000 to $40,000, and average around $27,500.[2] Vendors of GCs for field use include Foxboro, HNU Systems, MTI Analytical Instruments, Photovac International, and Sentex.

Gas Chromatography/Mass Spectrometer (GC/MS) systems start at $100,000.[3] Vendors of transportable GC/MS systems for field use include Bruker Instruments, Hewlett -Packard, Perkin-Elmer, Varian Associates, and Viking Instruments.

Photoionization Detectors and Flame Ionization Detectors

Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs) are used to detect organics in air. Applications include site and waste characterization, industrial hygiene monitoring, health and safety monitoring, contaminant plume delineation, and leak detection.

PIDs/FIDs can range in price from $4,000 to $25,000.[4] A typical system for field use will average $4,000 to $8,000.[5] PID/FID vendors include Foxboro, Heath, HNU Systems, MSA, Photovac, SRI, and Thermo Environmental Instruments.

X-Ray Fluorescence Analyzers

X-Ray Fluorescence (XRF) analyzers are used for detecting heavy metals and radionuclides in soils and sludges, and are emerging for detecting heavy metals and radionuclides in water. XRF usage is primarily for characterization of soil and ground water sites suspected of contamination by metals or mixed waste. Multiple compounds can be identified in a single sample.

XRFs can range in price from $14,000 to $77,000 with a typical instrument for field use costing from $30,000 to $50,000.[6] XRF vendors include Advanced Analytical Products and Services, Asoma Instruments, HNU Systems, Scitec, and TN Spectrace Technologies.

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[1] Vendor FACTS (Computer Program).. Washington DC: United States Environmental Protection Agency, January 1996.
[2] Vendor contacts.
[3] Vendor FACTS.
[4] Vendor FACTS.
[5] Vendor contacts.
[6] Vendor FACTS.

Immunoassay Kits

Immunoassay (IA) kits are available for detecting the concentration of a number of organics and hazardous chemicals in soil and a few contaminants in water. Coverage of currently available kits includes benzene, dioxins, mercury, trihalomethanes (THMs), trinitrotoluene (TNT), and polychlorinated biphenols (PCBs). Tests for other contaminants are coming to market rapidly. IAs are used primarily for site and waste characterization at remediation sites, but also are finding other niches in areas such as industrial process testing and PCB detection in transformer oil.

While IA kits are not instruments in the strictest sense of the word, they are a field technique for environmental analysis. When the term "field instrument" is used in this report, it is meant to include IA test kits.

The extremely low cost of IA tests, from $10 to $60 per test, is driving the rapid acceptance of this method.[1] While still under a $14 million market,[2] the sudden emergence of an easy to use, reliable, low-cost characterization method is perceived as a threat by many in the laboratory industry. In fact, IAs have been cited as the primary reason for falling prices of many sample analyses at environmental laboratories.[3]

IA tests range from $10 to $60, with a typical test costing from $10 to $20. The number of tests required at a site may vary from just a few to hundreds or even thousands. Many IA tests are available in lots of up to 1,000, with an average order numbering around 500. For those doing just a few tests, the low capital cost makes IA tests an attractive alternative to laboratory analysis. IA suppliers include EnSys, EM Science, Millipore, and Ohmicron Environmental Diagnostics.

Other Instruments

A number of commercially available technologies were not directly cited by interviewed equipment users for environmental field applications. Nevertheless, they compose a sizable portion of the environmental instrumentation market.

Many small, low priced sensors operate on electrochemical principles for selectively detecting inorganics in air or water. Theses sensors quickly

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[1] Vendor FACTS.

[2] Vendor contacts.

[3] “Environmental Instrumentation on Global Course”. Also International Association of Environmental Testing Laboratories and TechKNOWLEDGEy Strategic Group.

identify an ion concentration for elements such as chlorine, sulfur, copper, or fluorine, or gas concentration for carbon dioxide, chlorine gas, hydrogen sulfide, nitrous oxides, or one of many others. Applications include personal alarm monitors, combustible gas monitors, dissolved oxygen sensors, and ion specific sensors.[1] There is widespread use of these monitors for industrial process monitoring and ambient air monitoring, with a small portion of these applications falling within the scope of this project. Vendors of electrochemical sensors include Aldrich Chemical Company, Control Instruments Corp., GasTech, Interscan, and Phoenix Electrode Corp. for gases and Brinkmann, Innovative Sensors, Leeds & Northrup, and Rosemount for ions.

Open-path Fourier Transform Infrared (FTIR) Spectrometers detect organics in air. Their use is primarily for Continuous Emissions Monitoring (CEM) but they may also be used for ambient air monitoring. FTIRs typically cost around $25,000.[2] Manufacturers include ETG, Foxboro, KVB Analect, Nicolet Instruments Corp., and Perkin-Elmer.

Fiber Optic Chemical Sensors (FOCS) and analyzers are used to detect organics in water or soil vapor. They can detect benzene, toluene, ethyl benzene and xylene (BTEX), total petroleum hydrocarbons, and volatile organics. FOCS is well suited for in-situ testing of soil and water for areas such as plume characterization and leak detection. An analyzer will typically cost from $5,000 to $10,000.[3] Vendors include FCI and ORS.

With this background of some of the equipment used for environmental field analysis, the market can be analyzed in terms of buyers, sellers, sales, and market potential.

The Market

After examining environmental field sensing technologies, it is tempting to evaluate the market for instruments by technology. However, the market does not look at technologies as much as applications. A potential equipment user in not interested in an XRF analyzer per se, but in a technique for detecting a certain level of a metal in a soil. It is the measurement which is important to the buyers in the market, not the technology. An informed equipment user recognizes XRF as an attractive technology, but may consider

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[1] United Stated Department of Energy, Hazardous Waste Remedial Actions Program (Hazwrap), Literature Search, Review, and Compilation of Data for Gas Chromatography Sensors and Electrochemical Sensors. Oak Ridge, TN: U. S. Department of Energy, 1994.
[2] Vendor FACTS.
[3] Vendor FACTS.

alternatives. The previous technology examination provides a backdrop to an application-oriented market analysis.

Information regarding instrumentation applications can be used to derive a picture of the market. The following pages describe two methods be used to develop a market estimate. The first calculation begins with an estimate of overall instrument sales and divides the number into smaller pieces to determine the size of various market segments. The second method builds up the various market segments based on estimated number of units sold and average cost per unit. The results of each approach are then compared for a more reliable market estimate.

As a background to these market estimates, we will first examine the composition of the market in terms of buyers and sellers.

Buyers

The demand for field environmental analysis instrumentation comes, obviously, from people who want to analyze chemicals in the field. This consists of owners and legally responsible parties at polluted and suspected polluted property, and firms contracted by these individuals. In general, this land has been contaminated by decades of uninformed waste disposal decisions.

The largest single owner of real property in the U. S. is the federal government. Much of this land has been contaminated by various defense and energy related activities over the past decades. Private industry also has a significant amount of contaminated property which needs to be addressed at currently operating and abandoned sites. A third, smaller group of owners of contaminated land are real estate investors, who must remediate a site prior to development or sale to another party. All three of these groups outsource much of their site characterization, waste characterization, and remediation processing to environmental consultants and environmental engineering firms. Even currently operating manufacturing facilities with considerable environmental expertise on-site turn to environmental consultants when conducting a site remediation.

The number of potentially contaminated sites in the U. S. is staggering in size. The number of sites serious enough to be listed on the EPA's National Priority List (NPL) is 1,270,[1] and the number of sites which could be

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[1] United States Department of Commerce, Bureau of the Census, Statistical Abstract of the United States: 1994 (114th edition.) Washington DC, 1994.

potentially contaminated has been estimated in the hundreds of thousands.[1] At 9,700 domestic military facilities, the number of sites identified as potentially contaminated is 27,700 with 13,000 considered serious enough for action.[2] These numbers illustrate the enormity of the situation, and the long term need for environmental field instruments.

The overall U. S. market for soil and ground water remediation is approximately $12 billion annually.[3] About 1/3 of this spending can be attributed to the federal government, and about 2/3 to private industry. The market has been characterized as flat but stable as government and industry work their way through the formidable number of sites. Government environmental spending was $3.4 billion (35% DOE; 27% DOD; 38% EPA) in 1992 and is expected to grow to $11.2 billion (46% DOE; 20% DOD; 34% EPA) in 1999.[4]

Characterization of sites and waste, and monitoring of the environmental remediation process can account for anywhere from 0 to 40% of the total project cost, with the average being 15%.[5] In a $12 billion market, this equals $1.8 billion. The remaining $10.2 billion is spent on other steps in the remediation process such as waste treatment, storage, and final disposal.

Based on the results of our surveys, and other secondary sources, the various components of the $1.8 billion expenditures on characterization and monitoring have been identified and their size estimated. This breakdown is shown in the following figure. The total amount spent on off-site laboratory sample analysis for remediation characterization and monitoring is $600 million annually.[6] Expenditures on instruments for characterization and monitoring in the field total $140 million annually.[7] The remaining characterization expenses such as site deployment, sample collection, and labor is estimated to be $1.06 billion. Based on our discussions with environmental field engineers, the majority of this activity is for site characterization, with under a quarter of the expenditures going toward waste characterization and remediation process monitoring. In fact, no cases of field

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1 Rubin, Debra K. "Groundwater Cleanup Realities Test Old Ways, New Approaches". Engineering News-Record. August 15, 1994. p. 30.

2 Rubin, Debra K. et. al. "Base Cleanups Face New Era of Cuts and Commitments". Engineering News-Record. April 6, 1995.

3 Carey, John. "Can Flowers Cleanse the Earth?" Business Week. February 19, 1996. p. 54. This McGraw-Hill estimate reconciles a number of other third party market estimates from $9 billion (Environmental Business International as cited in Chemical Engineering, January 1996 p. 39 and other sources) to $20 billion.

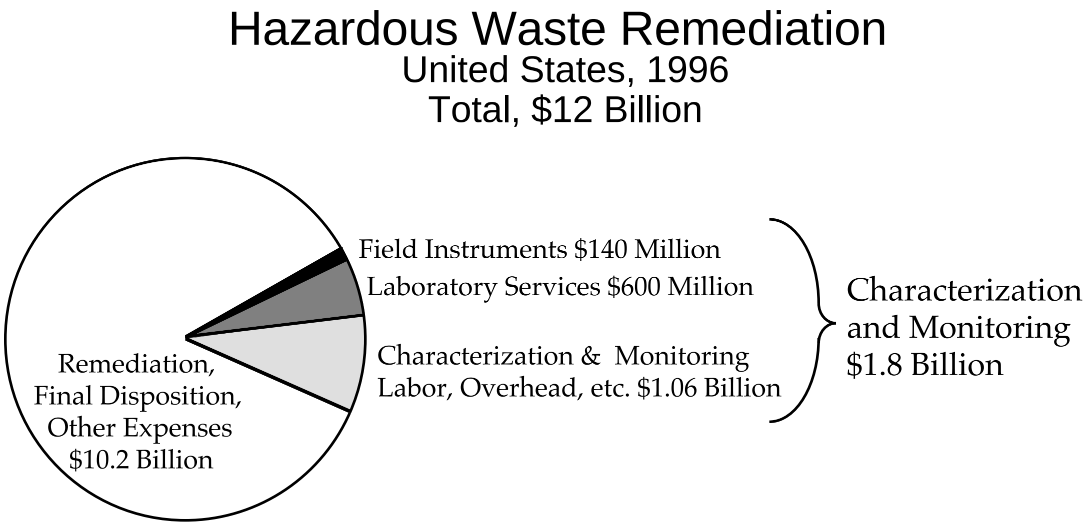
4 Park, Drew and Wahtola, Charles H. "Where is the Environmental Market Headed?" Engineering News-Record. June 6, 1994. p. E-9-17.

5 Based on interviews of technology users conducted for this project.

6 Based on data supplied by TechKNOWLEDGEy Strategic Group.

7 Derived later in this section.

instrument purchases specifically for remediation process monitoring were encountered in our surveys. Instruments used for remediation process monitoring are originally purchased for other purposes. These estimates for characterization and monitoring expenditures will be the basis of our market potential estimates derived later in this section.



A very large number of national and local engineering firms supply environmental remediation services. Pollution Engineering places the number of environmental consulting firms at 5,000.[1] The top 40 environmental engineering firm had 1995 revenues of about $3.7 billion in the U. S.[2] These largest firms together have approximately 1,000 offices across the U. S.[3] Small and medium sized environmental engineering firms have about 4,000 offices and share the remaining $8.3 billion of the remediation market. Similar to the environmental laboratory industry, environmental consulting and engineering underwent extensive growth in the 1980s. A subsequent leveling off of the market in the 1990s has led to a consolidation of environmental consulting and engineering firms with several large companies merging or acquiring other companies. Even after these mergers, the market remains highly fragmented.

Environmental service providers are not the only users of environmental field instrumentation, but account for over half of the market. The other portion of the market includes government and private industry.

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[1] Claussen, John H. "How to Select a Consulting Firm", Pollution Engineering, August 1994, p. 34.

[2] Tulacz, Gary J. "The Top 400 Contractors." Engineering News-Record. May 23, 1994. p. 40-60 and Unimar estimates.

[3] Tulacz, Gary J., PhoneDisc, and Unimar estimates.

Environmental services, however, spend a much larger proportion of revenues on environmental instrumentation. A percentage breakdown of users of environmental instrumentation is provided later in this section on page 2-19.

Sellers

According to U. S. Bureau of the Census data, over 3,200 establishments in the U. S. manufactured instruments in 1994.[1] This includes instruments which measure time such as watches and clocks, flow meters, medical instruments, photography supplies, and instruments for chemical concentrations. The number of suppliers of instruments for environmental field instruments is estimated to be 400,[2] with less than 50 vendors deriving their revenue exclusively from environmental field instrumentation. For many vendors, environmental field instrumentation is only a niche or sideline market.

Many suppliers and potential suppliers of environmental field instrumentation recognize that the market is not fully developed. Among the reasons cited for field instruments not approaching their full potential are that users are satisfied with current sampling and laboratory methods, that field instruments must be simple to operate before they are accepted, and reliability concerns from users and regulators. However, many users and vendors predict that it is only a matter of time before more analysis is performed in the field.

One final note on suppliers of field instruments is that there is a notable rental aspect of the market. Of the users interviewed, three of thirty stated that their company prefers to rent field instruments. While this is not statistically significant, perhaps five percent of the sales in the market are in the form of rental equipment. While a few vendors directly rent or lease equipment which they manufacture, the primary rental channel is equipment rental companies.

The volume of environmental field analysis equipment sales by all vendors in the U. S. in 1996 is estimated to be $140 million. This estimate is based on two different calculation methods. The first method arrives at an estimate by analyzing the larger instrumentation market. The second method builds a picture of the market based on unit sales projections. Each derivation is explained on the following pages.

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[1] United States Department of Commerce, Bureau of the Census. Statistical Abstract of the United States: 1994.
[2] United States Department of Commerce, Bureau of the Census. Statistical Abstract of the United States: 1994, and estimates.

Break-down Estimate

The principle behind the breakdown estimate is straightforward. Find the most reliable, most closely related market estimate and break the value down into components until one component is the market for environmental field instrumentation. One common starting point is federal government data.

The U. S. Department of Commerce has calculated that total instrument sales in 1994 was $63 billion, including $6.2 billion of process control instrumentation, and $4.9 billion of analytical and scientific instrumentation.[1] Process control instrumentation is primarily for industrial process control but includes environmental process control. Analytical and scientific instrumentation includes instruments used in the medical, chemical, and environmental industries. Together, these values encompass the instrumentation used for environmental field instrumentation. For certain instruments, such as Gas Chromatography, more detailed data is available, but again this data includes GCs for all applications.

Two disadvantages were apparent with going forward with an estimate based on this census data. First, while highly reliable, the data was considered too general for our purposes. A number of other industries would have to be analyzed to determine the amount of instrumentation which is used for environmental analysis, and then the amount of that instrumentation which is used in the field. Also, the data was several years old. Before going forward with this calculation, a more specific, more current data source was sought.

The December, 1995 issue of the Environmental Business Journal focused on environmental instrumentation. Its coverage included instrumentation used by environmental consultants, private industry, and government for laboratory analysis, process monitoring, and field analysis. The global current sales of environmental instrumentation for these categories was placed at $2.5 billion. The amount of this which consists of sales in the U. S. is 46%, or $1.2 billion.[2] This value is the result of a large amount of independent research, and aligns well with the census data.

The Environmental Business Journal also attributed the sales of environmental instrumentation to various end-use market segments as shown on the next page.

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[1] United States Department of Commerce. Current Industrial Reports: Selected Instruments and Related Products.
[2] "Environmental Instrumentation on Global Course".

Instrument Distribution by End-Use Market

End-Use Market	Instruments
Commercial Laboratories	20%
Government	20%
Chemicals Manufacturers	9%
Automobile Industry	9%
Petroleum Industry	8%
Water and Waste Water Utilities	8%
Environmental Consultants	6%
Utilities	5%
Other	15%

Using this data as a starting point, a break-down estimate was calculated for environmental field instruments.

The Environmental Business Journal estimate did not include industrial process instrumentation which is considered to be environmental. Therefore, $600 million for industrial process instrumentation was added to the $1.2 billion of environmental instrumentation. This industrial process instrumentation will be taken out again in our calculation, but is included for completeness. The total market for environmental instrumentation is therefore taken to be $1.8 billion.

The amount of *field* instrument sales was modeled from the $1.8 billion of *total* environmental instrumentation based on applications within each industry. For example, the entire amount of sales for commercial laboratories was considered to be laboratory equipment. Similarly, since the primary use of instruments for utilities is for on-line monitoring of process water and emissions, most of the instruments in this segment were considered to be process monitoring instrumentation. For each industry, field instrumentation was defined to include site and waste characterization equipment, and environmental remediation process monitoring equipment. After each industry's field instrument sales had been modeled, a total was calculated.

The results of these calculations are shown in the table on the next page. Each cell in this table should not be taken as absolute, but as an intermediate estimate. Extensive research would be required to determine, for example, if the amount of process monitoring equipment used by water and waste water utilities was precisely $126 million. Each value falls within a resonable range, and each of the totals are very close to what vendor data and independent data indicate as market totals.

Instrument Sales by End-Use Market

End-Use Market	Total U. S. Sales	Process Monitor.	Lab Analysis	Field Analysis
Commercial Lab	360	-	360	-
Gov. - EPA, DOD, DOE	360	29	317	14
Water & Waste Water Util.	144	126	7	11
Environmental Consulting	108	27	12	69
Chemicals	162	134	13	15
Petroleum	144	112	20	12
Utilities	90	84	-	6
Automotive	162	160	-	2
Other	270	251	5	14
Total	1,800	924	734	*142*

Each value is in millions of current dollars.

The total market for environmental field instrumentation in 1996 is estimated at $142 million by this method.

An alternative method for arriving at a total market estimate is to build the estimate based on estimates of the total sales of each type of instrument. This calculation is performed next.

Build-Up Estimate

This model for the volume of sales derives the total sales from the number of potential equipment users. A chain-ratio calculation is used, multiplying the number of establishments by the percent which will use the instruments, the percent which would buy instruments each year, the number of instruments each buyer would purchase, and the average cost of each instrument. As we will see, this yields an estimate for the total market size.

$$\begin{matrix}\text{End-Use} \\ \text{Market}\end{matrix} = \begin{matrix}\text{Number of} \\ \text{Establishments}\end{matrix} \times \begin{matrix}\text{\% Using} \\ \text{Field Inst.}\end{matrix} \times \begin{matrix}\text{\% In the} \\ \text{Market,} \\ 1996\end{matrix} \times \begin{matrix}\text{\% Buying,} \\ 1996\end{matrix} \times \begin{matrix}\text{Average} \\ \text{Number} \\ \text{Purchased}\end{matrix} \times \begin{matrix}\text{Average} \\ \text{Cost Per} \\ \text{Instrument}\end{matrix}$$

$$\begin{matrix}\text{Total} \\ \text{Market}\end{matrix} = \sum \begin{matrix}\text{End-Use} \\ \text{Markets}\end{matrix}$$

The starting point for this estimate is the number of establishments for each type of environmental field instrument user. Data for the number of establishments was taken from Census data, and other sources.[1] The total number of establishments overstates the market. For example, the number of "Other" manufacturers is over 400,000, while the number who might consider purchasing environmental field instrumentation is a small fraction of this total. In each area, the number of establishments in the environmental field instrument market is relatively small. These values have been estimated by subtracting a majority of the smaller establishments, who would not be likely to make a capital investment in field instruments with a limited use, and subtracting the portion of larger firms who would not have environmental field instrument applications. The number of establishments which are likely to use environmental field instruments is shown below for each end-use market.

Number of Establishments by End-Use Market

End-Use Market	Establishments Likely to Use Field Instruments
Government	2,500
Water & Waste Water Utilities	800
Environmental Consulting & Services	5,500
Chemicals	2,000
Petroleum	1,500
Utilities	2,000
Automotive	500
Other	12,000

A number of other factors must be applied to these values before the market can be determined. This includes the percent of establishments in the market, the percent in the market likely to buy, and the number of instruments bought by each user. Precise values for each of these factors are difficult to obtain, but reasonable estimates were determined through discussions with equipment users, equipment vendors, and other industry experts.

The first factor applied to the number of establishments is the percent considering the purchase of equipment in the next year. Just because a site is likely to use field instruments does not mean that they are actually using the equipment, nor that they are in the market to purchase the equipment in a

[1] United States Department of Commerce, Bureau of the Census. Statistical Abstract of the United States: 1994, PhoneDisc. Claussen, John H.

given year. The next ratio is the percent of users in the market who will actually make a purchase in the year. The final step in finding the number of instruments sold is determining the average number of instruments purchased by each buyer in the market for the year. The most helpful example of the need for this calculation is Immunoassay kits, which can be purchased singly, but are also purchased in hundreds or thousands. Each of these factors was applied to each of the end-use markets for each instrument encountered in the course of the interviews. The results of the calculations are shown below. Again each cell in the table should not be taken as absolute, but as an intermediate estimate. The total values for each instrument sales, however, falls within vendor estimated ranges.

Number of Instruments Purchased by End-Use Market

End-Use Market	Estab.	GC/MS Units	PID Units	FID Units	XRF Units	IA Units
Government	2,500	250	275	175	70	75,000
Water & Waste Water Util	800	16	24	12	8	24,000
Environmental Services	5,500	1,155	2,310	1,650	165	233,750
Chemicals	2,000	220	800	480	12	80,000
Petroleum	1,500	150	600	360	9	67,500
Utilities	2,000	20	80	80	0	80,000
Automotive	500	5	10	5	3	2,500
Other	12,000	120	240	180	72	12,000
Total	-	1,936	4,339	2,942	339	682,750

A final market estimate may be derived by multiplying the number of instruments purchased by the average cost. Average costs were obtained from vendor interviews and equipment databases.

Up to this point, the market estimate has only considered the five types of instruments which were repeatedly mentioned in the user interviews conducted for this project. Other types of instruments are known to be used for site characterization, waste characterization, and remediation process monitoring such as Fiber Optic Chemical Sensors (FOCS), Electrochemical Sensors, and Fourier Transform Infrared (FTIR) devices. The total sales of these instruments for environmental field applications is estimated to be $20 million.

The final market build up estimate is shown on the top of the next page. The final result of this process is an estimate for 1996 sales of environmental field instruments of $137 million. Additionally, this estimate reveals which commercial markets may be considered most attractive in terms of current sales.

Instrument Market by Instrument Type

Environmental Field Instruments	Units	Average Cost	Total Market $ 000
GC / MS	1,936	27,500	53,240
PID	4,339	4,000	17,356
FID	2,942	7,000	20,594
IA	682,750	20	13,655
XRF	339	35,000	11,865
Other instruments			20,000
Total			$136,710

The validity of this process has been evaluated against vendor estimates in a number of areas, and against the previous break-down market estimate. This value compares favorable with vendor estimates of individual instruments and of total instruments.

Market Estimate

The overall market size has been estimated by two different methods to be $142 million and $137 million. As the accuracy of each estimate is order of magnitude, a compromise estimate of $140 million will be taken as the current value of the market for environmental field instruments.

The growth of the market has been described by different sources as both explosive and illusory[1]. The reality is that the market is experiencing above average growth, and a consensus forecast is 7% per year. This growth can be attributed to more reliable, lower cost, more rugged, easier to use equipment. Even with this higher than average growth, the full potential of the market will not be approached in the near term. The final portion of our market analysis is examining the potential of the market.

Market Potential

Any estimate of market potential in a field with high levels of research and development should consider three elements:

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[1] "Environmental Instrumentation on Global Course". Also Basta, Nicholas and Veasey, David. "Environmental Firms React to a Cooler Market". Chemical Engineering. January, 1996. p. 39. and other market estimates and Unimar modelling.

- Potential growth of existing products;
- Potential growth from improvements in existing technology;
- Potential sales of currently non-existent products - even those not yet in development.

In this context, "market potential" is difficult to discern. Fortunately, a reference point is available for a market potential estimate - the current state of the art.

In the case of environmental field analysis, the current practices are utilizing available field instruments with heavy reliance on laboratory services, as shown in the figure on page 2-14. An assumption for our market potential estimate is that users would be willing to increase their purchases of field instruments only as much as they would reduce their expenditures on laboratory analysis and other characterization and monitoring activities. This assumption will allow us to estimate the market for existing equipment, modified equipment, and currently non-existent equipment. Current characterization and monitoring expenses are summarized below.

Characterization and Monitoring Expenditures

Field Instruments	$140 Million
Laboratory Services	$600 Million
Other Expenses	$1,060 Million
Total	$1,800 Million

Market potential may be estimated in the short term or the long term with a number of assumptions. The short term refers to a period of time short enough that the market buyers and suppliers have very little time to react to new product demands, increases in prices, or other major changes. The long term refers to a longer period of time, where significant market adjustments can be made. Due to the long budgeting process for environmental field instrumentation, we will define the short term to be 2 years. Due to the long product development and testing cycle, as well as the period of time for new techniques to become generally accepted, we will define the long term to be 10 years. We will derive maximum, optimistic, and expected market estimates in the near and long term using current expenditures for environmental characterization and monitoring equipment as a starting point.

The value of field instruments replacing laboratory analysis will not be a $1 to $1 relationship. For a user spending $20,000 on sample collection and laboratory analysis, a $20,000 field instrument is not necessarily an attractive alternative. First, the instrument must be able to do all of the currently laboratory based analysis in the field. Second, other costs associated with the purchase of the equipment are maintenance, consumables, and most importantly labor. On the other hand, the savings associated with field analysis are time, documentation, efficiency, and even potential tax savings. The useful life of the instrument may also span several years. For the purpose of our estimates, we will assume that an instrument will be purchased if it costs no more than a conservative 40% as much as the expenses which it replaces.

Short Term Market Potential

In the short term, buyers and suppliers in the market do not have time to react to changing market conditions. For the short term, we will use an annual market growth rate of 7%. Returning to the figure on page 2-14, this growth rate can be thought of as a combination of a growing pie overall, growing amount of characterization and monitoring, and increasing amount of field analysis as a portion of characterization and monitoring expenditures. Any growth over 7% would be due to an acceleration of these natural growth effects.

In the short term, the maximum market potential would be if field instruments completely replaced all characterization alternatives. This would be the sum of $140 million currently spent on field instruments, and 40% of the other characterization expenditures of $1.66 billion for a total of $804 million. In 2 years, at 7% annual growth, the maximum short term market potential will be $920 million. This maximum is the amount the market is willing to spend for completely automatic equipment which performs the entire characterization or monitoring process without labor or other costs. It is impossible that the short term market will reach this maximum potential, as no such instruments exist.

Maximum Short Term Market Potential

Field Instruments		$140 Million
Laboratory Services	$600 Million x 40% =	$240 Million
Other Expenses	$1,060 Million x 40% =	$424 Million
Total		$804 Million

$$\$804 \times (1.07)^2 = \$920 \text{ Million per year}$$

An optimistic market potential estimate will assume that increased regulator acceptance will allow field instruments to capture 10% of the sampling effort and expense associated with laboratory analysis, and produce a 5% reduction in characterization and monitoring expenses. This estimate results in $140 million in current instrument sales plus 40% of $60 million in displaced laboratory services plus 40% of $52 million in displaced characterization and monitoring expenses for a total of $184 million in 1996. At 7% annual growth, this would be $212 million in two years.

Optimistic Short Term Market Potential

Field Instruments		$140 Million
Laboratory Services	$600 Million x 10% x 40% =	$24 Million
Other Expenses	$1,060 Million x 5% x 40% =	$20 Million
Total		$184 Million

$$\$184 \times (1.07)^2 = \$212 \text{ Million per year}$$

An estimate of the expected market assumes that the current market forces will allow the current market to grow at a 7% annual rate, for a total market of $160 million.

Long Term Market Potential

In the long term, a number of considerations will allow the market to react to changing market conditions, making the long term estimates more complex.

Falling costs will increase the market's potential growth rate. The natural growth of the market has been estimated at 7%. An assumption behind the market potential is that in order for a product to gain market acceptance, the cost of the product must be lower than currently accepted practices. A widely documented additional benefit of falling costs is increased usage. For example, as the cost of computing has fallen, applications developed have spread from scientific calculations to accounting, word processing, general business uses, and entertainment. While field instruments will obviously not permeate society as computing has, falling cost will increase the amount of analysis performed overall. For our maximum and optimistic estimates, we will take the impact of this cost effect to increase the market's potential growth rate to 10%. Returning to the figure on page 2-14, this high growth rate may be thought of as a combination of a growing pie, and a growth of characterization and monitoring as a portion of the pie.

A long term maximum market potential would be the sum of $140 million currently spent on field instruments, and 40% of the other characterization expenditures of $1.66 billion for a total of $804 million. In 10 years, at 10% growth, the maximum short term market potential will be $2.1 billion per year. Even in the long term this maximum potential should be taken as an unrealistic upper bound to our calculations, since the current level of product research does not suggest equipment which could completely replace laboratory analysis and field labor at the suggested cost.

Maximum Long Term Market Potential

Field Instruments		$140 Million
Laboratory Services	$600 Million x 40% =	$240 Million
Other Expenses	$1,060 Million x 40% =	$424 Million
Total		$804 Million

$$\$804 \times (1.10)^{10} = \$2.1 \text{ Billion per year}$$

It is unlikely that field analysis will even completely replace laboratory analysis. Independent confirmation of results may be necessary in some cases, and smaller firms are unlikely to purchase equipment which requires an investment of capital and personnel. An optimistic estimate for a ten year period would be that 40% of laboratory analysis will be displaced, along with 20% of other expenses. This yields a total of $321 million of current expenditures, or $757 million per year in 10 years.

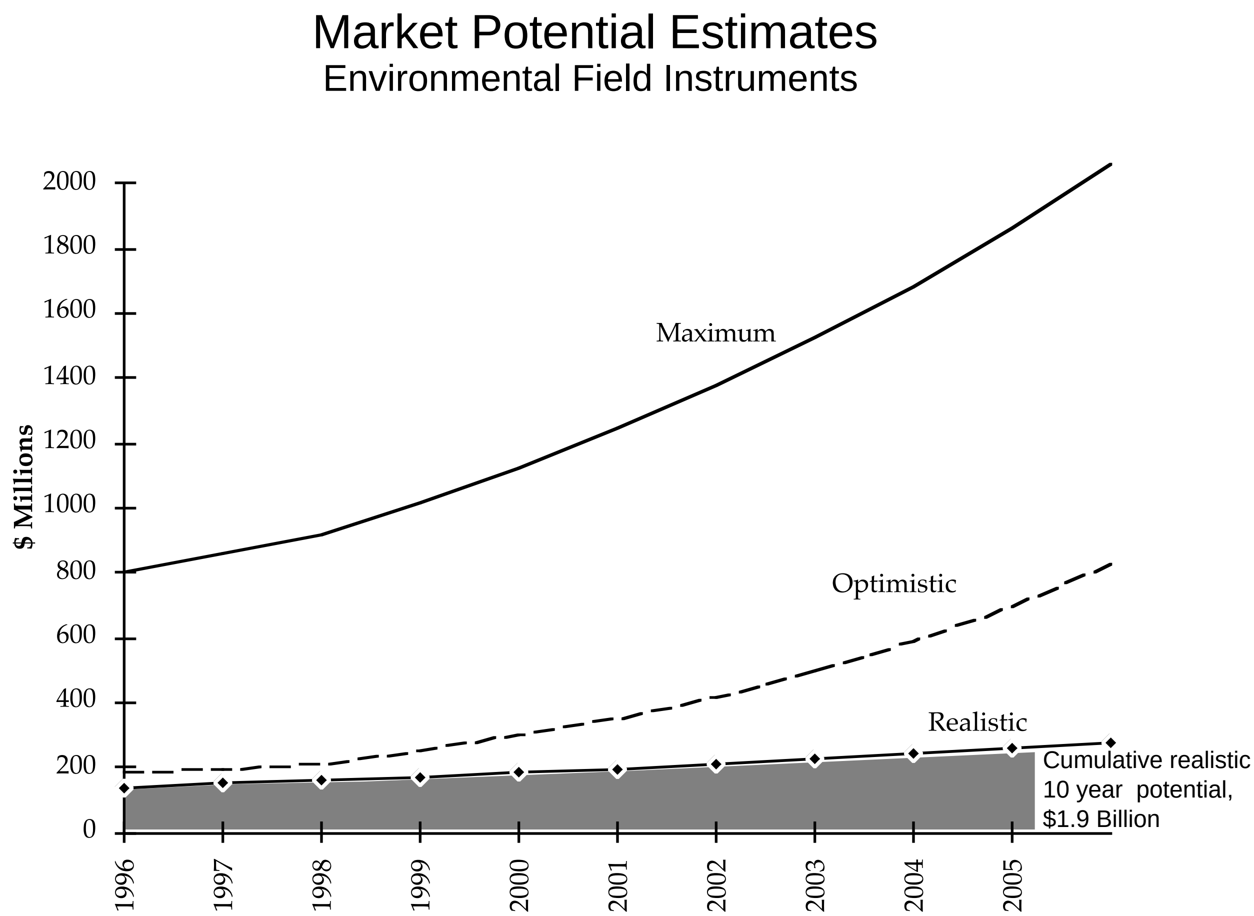
Optimistic Long Term Market Potential

Field Instruments		$140 Million
Laboratory Services	$600 Million x 40% x 40% =	$96 Million
Other Expenses	$1,060 Million x 20% x 40% =	$85 Million
Total		$321 Million

$$\$321 \times (1.10)^{10} = \$757 \text{ Million per year}$$

The expected market size in ten years assumes a 7% growth rate on $140 million of current sales for a value of $275 million per year in 10 years. The total cumulative sales over the 10 year period will be $1.9 billion. In the next section we will consider the market potential of individual market needs as a percentage of this cumulative market potential of $1.9 billion over the ten year period from 1996 to 2005.

An important note regarding these market potentials is that they have been derived for the *environmental field instrumentation* market. They do not consider the potential for sales in other markets. Just as environmental remediation process monitoring has been only a small portion of the applications of field instruments in the environmental sector, environmental remediation process monitoring is only a small portion of the much larger industrial process monitoring market.



Market Potential Estimate Summary
Environmental Field Instruments

	Maximum	Optimistic	Realistic
Short Term Market Potential	$902 Million	$212 Million	$160 Million
Long Term Market Potential	$2.1 Billion	$612 Million	$275 Million
Cumulative Long Term Market Potential			$1.9 Billion

This study has examined the environmental field instrument market and has not attempted to estimate current sales or future potential for markets *related* to environmental field instrumentation, such as industrial process monitoring and personal safety monitoring. It appears that each of these markets are an order of magnitude larger than the market for environmental field instruments. For example, the U. S. Department of Commerce reports the sales of process control instruments in 1994 to have been $6.2 billion, and miscellaneous measuring and controlling devices as $3.8 billion.

For many instruments, only five to twenty percent of overall sales may be for environmental field applications. Other significant instrument markets include industrial, medical, and transportation markets. Although this study did not examine these markets, technology developers must consider related markets for an instrument in new product development decisions.

The final portion of our market analysis is an examination of the needs which have been identified by equipment users both within the Department of Energy and in private industry.

Needs

A significant emphasis of the project was to identify and document unmet needs in the marketplace. A set of needs documented within each DOE focus area was analyzed prior to the user interviews as a basis for the survey instrument. These needs were later revisited, taking non-DOE equipment user comments into account. An important final output of this project is a set of needs ranked using various criteria to provide insight for technology developers.

As an introduction to these market needs, we will first examine the needs identified for site characterization, waste characterization, and remediation process monitoring equipment within the DOE.

A large number of needs have been identified within the DOE. After analyzing this information, and consulting with non-DOE equipment users, these needs were found to be quite comprehensive. A method was required to translate these various needs into a list which was meaningful, yet manageable. A functional needs description was derived to address this concern.

Each need was classified on a functional basis. This required very general needs to be broken into a number of separate needs, and very specific needs to be summarized. An example will elucidate the nature of the needs statements encountered, and how they were reconciled. One needs statement from a DOE focus area reads:

> There is a need for a compact, portable, real-time analytical instrument using the active nitrogen energy transfer (ANET) technique to quantify concentrations of specific hazardous components including hydrocarbons, both polychlorinated and nonchlorinated, transuranics, uranium, thorium, and heavy metals including mercury, chromium, cadmium, arsenic, and lead.

The beginning of this statement, "There is a need for a compact, portable, real-time analytical instrument" is interpreted to encompass implied characteristics of a field instrument. The individual characteristics are not the focus of the need. Separating each of these characteristics would make the total number of needs overly cumbersome. Overly detailed needs statements would be neither meaningful nor manageable.

The next portion of the statement, "using the active nitrogen energy transfer (ANET) technique", was disregarded. While ANET technology may show promise, the technology used is assumed to be irrelevant to the equipment user. If a technology superior to ANET met the detection criteria stated at a lower cost, it would make the ANET technology obsolete. Therefore references to specific technologies were not considered to be integral to a need.

The final portion of the statement was taken as the focus of the need - "to quantify concentrations of specific hazardous components including hydrocarbons, both polychlorinated and nonchlorinated, transuranics, uranium, thorium, and heavy metals including mercury, chromium, cadmium, arsenic, and lead." To list this need by each specific contaminants would not really be meaningful, and it would make the number of needs statements overly cumbersome. Instead, identifying specific contaminants within a class of contaminants was defined as a single need. In our example, three classes of contaminants are listed, organics, radionuclides, and heavy metals. Detecting a class of contaminants in a specific media was considered to represent a different need. No specific media was listed for this need, but the need was for site characterization, and was assumed to address soil, subsurface soil, water, and ground water. The final classification of this need was to measure each of three contaminant classes in four media which results in a total of twelve functional needs.

This example was neither the most specific nor the most general needs statement encountered. In cases where the functional requirements were discernible, needs were divided into multiple parts and added to a database of needs statements. In a few exceptional cases, DOE needs statements were disregarded as being too general, such as a need to "monitor the retrieval process" of hazardous waste tanks. It was not possible to determine which wastes are of concern from the needs statements, and it is likely that the functionality of the need had been covered by more specific needs such as monitoring various contaminants in air and in soil. Other needs statements were disregarded as not applying to chemical analysis. For example, a need to map the subsurface ground water movement, which may be necessary for certain remediation efforts, is not directly aided by chemical field instrumentation.

It should be noted that just as a single need may be divided into multiple needs, a single instrument may address multiple functional needs. For example, it may be possible that a single instrument could detect organics, radionuclides, and heavy metals in soil, subsurface soil, water, and ground water.

Another distinction was made for the final needs classifications. In addition to defining each need in functional terms of contaminant and media, a third functional criteria was also considered to be important. An instrument which can sense a contaminant in ground water or sub-surface water has an additional function - sub-surface sensing - which is important to the instruments operation. Therefore a need for sensing a contaminant in subsurface water is considered to be distinct from a need for sensing a contaminant in water. Again, a single instrument might be able to meet both of these functional needs.

The result of an analysis of the DOE needs statements was a comprehensive database of needs for new or improved sensor systems and field deployable analytical instrumentation. Elements in the database include the sources of the need, frequency of citation, and relevant applications. Each need represents needs within the DOE, since no needs encountered in the course of interviews fell outside of the DOE needs statements.

A summary list of the needs follows at the end of this section. Each needs statements describes a stated desire by users for a new or improved sensor for detecting a particular contaminant in a particular media. The assumptions are that the equipment needed is for field use, and therefore is compact, portable and real-time. For each need, attributes such as increased precision, lower cost, easier to operate, and safer to operate than existing equipment are considered to be additional goals of technology development.

The needs here are listed in two sets. The first set contains needs for detecting contaminants, the second set contains needs for monitoring contaminants. The needs are presented in no particular order. The detection needs more generally apply to site characterization and waste characterization, and the monitoring needs are for remediation process monitoring and site monitoring. Again, a single instrument with little or no modification may be able to meet multiple needs on both of these lists, such as detecting metals in soil and water and monitoring metals in soil and water.

<u>Need for an improved sensor for detecting (47 needs)</u>
Detecting individual radioactive metals in air
Detecting individual radioactive metals in water
Detecting individual radioactive metals in water in-situ
Detecting individual radioactive metals in soil
Detecting individual radioactive metals in soil in-situ
Detecting individual radioactive metals in sludge
Detecting individual radioactive metals in metal, concrete, other solids
Detecting individual radioactive contaminants in facilities remotely
Detecting radioactive metals in waste drums and boxes non destructively
Detecting individual radioactive metals on underwater concrete surfaces
Detecting individual radioactive metals in asbestos
Detecting minor radioactive constituents in solution with high transuranics
Detecting individual radioactives in high level waste tanks in-situ
Detecting physical properties of high level waste in tanks
Detecting radiological properties 3D mapped in field
Detecting individual RCRA metals in air
Detecting individual RCRA metals in water

Need for an improved sensor for detecting (continued)
Detecting individual RCRA metals in water in-situ
Detecting individual RCRA metals in soil
Detecting individual RCRA metals in soil in-situ
Detecting individual RCRA metals in sludge
Detecting individual RCRA metals in metal, concrete, other solids
Detecting RCRA metals in waste drums and boxes non destructively
Detecting individual RCRA metals in asbestos
Detecting individual RCRA metals in facilities remotely
Detecting chemical properties 3D mapped in field
Detecting individual organics in air
Detecting individual organics in air in-situ
Detecting individual organics in water/ liquids
Detecting individual organics in water in-situ
Detecting individual organics in soil
Detecting individual organics in soil in-situ
Detecting individual organics in sludge
Detecting individual organics in metals, concrete, other solids
Detecting organics in waste drums and boxes non destructively
Detecting individual organics in asbestos
Detecting individual organics in facilities remotely
Detecting total organic carbon content in tank waste
Detecting DNAPLs in soil
Detecting DNAPLs in soil in-situ
Detecting DNAPLs in water
Detecting DNAPLs in water in-situ
Detecting other contaminants in water
Detecting other contaminants in water in-situ
Detecting other contaminants in soil
Detecting other contaminants in soil in-situ
Detecting general contaminants in drums and boxes in-situ

Need for an improved sensor for monitoring (21 needs)
Monitoring individual radioactive metals in air
Monitoring individual radioactive metals in water
Monitoring individual radioactive metals in water in-situ
Monitoring individual radioactive metals in soil
Monitoring individual radioactive metals in soil in-situ
Monitoring individual RCRA metals in air
Monitoring individual RCRA metals in water
Monitoring individual RCRA metals in water in-situ
Monitoring individual RCRA metals in soil
Monitoring individual RCRA metals in soil in-situ
Monitoring individual organics in air
Monitoring individual organics in water

<u>Need for an improved sensor for monitoring (continued)</u>
Monitoring individual organics in water in-situ
Monitoring individual organics in soil
Monitoring individual organics in soil in-situ
Monitoring DNAPLs in water in-situ
Monitoring other contaminants in air
Monitoring other contaminants in water
Monitoring other contaminants in soil
Monitoring other contaminants in soil in-situ
Monitoring other contaminants in sludge

"Other contaminants" includes compounds which did not fall into the primary classifications. These includes some inorganics, herbicides, and explosives.

The development of the needs list is an intermediate step toward ranking the individual needs for improved instrumentation. Needs could be ranked according to various criteria, with each ranking useful for different individuals. The most important ranking for technology developers is that of market potential. The top needs in terms of market potential have been identified in two different manners in the next section.

Needs Ranking

One of a number of different qualitative and quantitative characteristics could be chosen to rank user needs for new or improved environmental field instrumentation. Cost to bring to market, technology fit, market potential, or other characteristics all may have value in determining the most important market needs for various policy and technology developers. For the purposes of this market study, only market potential has been chosen to rank the needs. This criteria would be the most important for potential technology developers. The resulting ranking will not be an absolute listing of which market needs are of highest priority. In fact, one of the lowest needs in terms of market potential may by one of the most pressing in terms of protecting the public health. This list is meant only to act as one element which enters into the discussion of technology development for environmental field instrumentation.

At this point is it important to remember the level of detail of the needs statements. The needs are not listed for specific compounds, but classes of compounds in specific media. Examining the market potential for a sensor which detects benzene in water at 1 ppb is not practical at this detail level. What we would know about this market potential is that it is less than the total market potential for detecting organics in water. Also, the market potential for an instrument which detects organics in all media is not directly available from the ranking. The potential for this instrument would be the sum of all of the potentials for organics in all media.

For instruments which detect contaminants in ground water or subsurface soil, only the chemical sensing portion of the instruments cost savings have been taken into account. The cost associated with bringing samples to the surface is a significant driver behind the need for this technology, but is not obtainable with the means of this project. Most instruments which detect a contaminant in soil are functionally capable of detecting the contaminant in subsurface soil once a sample has been brought to the surface. Also, an instrument for detecting a contaminant in subsurface soil is likely to be able to detect at the surface. The distinction is made for the sensing portion of functionally different procedures.

Of course, these potentials do not capture all of the complexities of market dynamics. An instrument which meets many needs could not reach the full market potential of all of the needs, as many users are reluctant to purchase an instrument which exceeds their own particular requirements.

It is also important to remember that the market share of a single vendor will be less than the total market potential. A decidedly superior instrument with proprietary technology may be able to capture a large part of a market, but competing suppliers will enter attractive markets and limit any single vendors share.

Earlier, a total long-term market potential for environmental field instrumentation was estimated to be $1.9 billion. This potential is the cumulative total market over a ten year period. A quantitative method to allocate this market potential according to market needs was developed based on the results of the survey.

From the surveys conducted, we can quantify the relative importance of detecting various pollutants in various media, as well as the value of in-situ sensing opposed to extractive measurements. Two different portions of each of the surveys were used to allocate potential according to user perceptions of the relative importance of needs.

In Questions 1 to 6 for the characterization survey, questions were asked regarding the types of characterization performed, contaminants of concern, and methods employed. Similarly, Questions 1 to 6 in the monitoring survey concern remediation contaminants and methods. Based on the frequency that equipment which met each need was cited, values were assigned to each need.

In each survey, Question 9 asked the respondents to rate a number of hypothetical features of future equipment. Based on the responses given to each of the elements of the needs - detecting specific classes of contamination and detecting pollutants in specific media - the potential value of each need which has been unmet by existing technology was allocated.

The total of the market potential for each need was determined by combining the value of the market potential which is met by existing technology and value of market potential which will be met by future technology. Based on the size of our survey sample, none of these total market potential portion estimates can be considered statistically significant. Other factors such as sample bias may further reduce the accuracy of these estimates. On the other hand, the goal of these estimates is not to arrive at absolute values, but to determine the relative size of the market potential of various needs. The methods employed give an adequate approximation of the relative position for each market need compared to the others. The ranking of each need parallels what is known of the type of contamination at hazardous waste sites.

A ranking of the needs based on this market potential allocation is below. Two digits are shown to demonstrate the relative value of each need.

Needs Ranked by Percent of Market Potential

13%	Detecting individual organics in air
12%	Detecting individual organics in soil
7.0%	Detecting individual organics in water/ liquids
6.1%	Detecting individual RCRA metals in soil
5.7%	Detecting individual organics in soil in-situ
4.9%	Detecting individual RCRA metals in water
4.8%	Detecting individual RCRA metals in water in-situ
4.8%	Detecting individual RCRA metals in soil in-situ
4.0%	Detecting individual organics in water in-situ
3.2%	Detecting individual RCRA metals in air
3.2%	Detecting individual RCRA metals in sludge
2.8%	Detecting other contaminants in soil in-situ
2.7%	Detecting other contaminants in water in-situ
2.6%	Detecting other contaminants in soil
2.6%	Detecting individual organics in air in-situ
2.6%	Detecting individual organics in sludge
2.3%	Detecting other contaminants in water
1.7%	Monitoring individual organics in air
1.4%	Monitoring individual organics in soil
1.0%	Detecting individual radioactive metals in soil
0.92%	Detecting individual radioactive metals in water
0.87%	Monitoring individual RCRA metals in air
0.82%	Monitoring individual organics in water
0.75%	Monitoring individual RCRA metals in soil
0.63%	Detecting DNAPLs in soil in-situ
0.63%	Detecting individual radioactive metals in soil in-situ

Needs Ranked by Percent of Market Potential (continued)

0.61% Detecting DNAPLs in water in-situ
0.61% Detecting individual radioactive metals in water in-situ
0.61% Detecting individual radioactives in high level waste tanks in-situ
0.61% Monitoring other contaminants in air
0.60% Detecting DNAPLs in soil
0.58% Monitoring individual RCRA metals in water
0.52% Detecting DNAPLs in water
0.44% Detecting individual radioactive metals in air
0.44% Detecting individual radioactive metals in sludge
0.43% Monitoring other contaminants in soil
0.36% Monitoring other contaminants in water
0.35% Monitoring individual organics in soil in-situ
0.23% Monitoring other contaminants in sludge
0.23% Detecting individual RCRA metals in asbestos
0.23% Detecting individual RCRA metals in facilities remotely
0.23% Detecting individual RCRA metals in metal, concrete, other solids
0.23% Detecting RCRA metals in waste drums & boxes non destructively
0.19% Monitoring individual RCRA metals in soil in-situ
0.18% Detecting individual organics in asbestos
0.18% Detecting individual organics in facilities remotely
0.18% Detecting individual organics in metals, concrete, other solids
0.18% Detecting organics in waste drums and boxes non destructively
0.18% Detecting total organic carbon content in tank waste
0.12% Monitoring other contaminants in soil in-situ
0.11% Monitoring individual radioactive metals in air
0.09% Monitoring individual radioactive metals in soil
0.06% Monitoring individual organics in water in-situ
0.06% Monitoring individual radioactive metals in water
0.04% Monitoring individual RCRA metals in water in-situ
0.03% Detecting chemical properties 3D mapped in field
0.03% Detecting general contaminants in drums and boxes in-situ
0.03% Detecting individual radioactive contaminants in facilities remotely
0.03% Detecting individual radioactive metals in asbestos
0.03% Detecting individual radioactive metals in metal, concrete, solids
0.03% Detecting individual radioactive metals on underwater concrete surfaces
0.03% Detecting minor radioactive constituents in solution with high transuranics
0.03% Detecting physical properties of high level waste in tanks
0.03% Detecting radioactive metals in waste drums & boxes non destruct.
0.03% Detecting radiological properties 3D mapped in field
0.02% Monitoring individual radioactive metals in soil in-situ
0.01% Monitoring DNAPLs in water in-situ
0.01% Monitoring individual radioactive metals in water in-situ

"Other contaminants" includes compounds which did not fall into the primary classifications. These includes some inorganics, herbicides, and explosives.

The highest need in terms of market potential is "Detecting individual organics in air" with a value of 13%. This can be interpreted as meaning that the market potential for an instrument which only detects organics in air is 13% of the total cumulative environmental field instrumentation market potential of $1.9 billion over 10 years. An instrument which can detect only organics as a class, or which can only detect a single organic such as benzene will have a lower market potential.

It is implied that an instrument which does not deliver results in real time, or has a small dynamic range could capture less than this total market potential. Also, an instrument from a single manufacturer will probably capture only a share of the total market. On the other hand, an instrument meeting multiple needs and applying to related applications such as personal safety monitoring will have a higher market potential. In order to approximate a market potential for a particular instrument, all of the market potentials where the instrument may apply must be totalled. This includes the market potentials estimated above, as well as any related markets which are not strictly environmental field instrumentation. Some examples of aggregation of these market potentials lead us to some conclusions regarding the potential for instruments of various types.

Suppose an instrument had been developed which was capable of identifying any individual organic material in any type of media, in-situ or extractive. If we were to total all of the market potentials where this instrument may apply, the market potential would be 55% of the total market of $1.9 billion over 10 years. If similar totals were calculated for the other major pollutant classes, they could be ranked as shown.

<u>Pollutant Classes Ranked by Percent of Total Market Potential</u>

55%	Organics
30%	Metals
10%	Inorganics and Other Pollutants
5%	Radioactive Metals

This shows that of instruments which can monitor or detect an individual organic in-situ or in a sample of air, water, or solid, the market potential would be 55% of the total. This larger number is now statistically significant. Based on the size of our survey, there is a 90% probability that the actual value is +/- 15% of this value, or from 40% to 70%. At this level of accuracy, the relative position for each market need compared to the others may be more certainly determined.

One other type of aggregated ranking provides insight in the general value placed on needs by the market. Totalling the market potential portions by pollutant media yields the ranking shown.

Pollutant Media Ranked by Percent of Total Market Potential

39%	Soil
29%	Water
23%	Air
7%	Solids / Sludges
2%	Non-destructive examination

Based on these market potential rankings of aggregated market needs, a few patterns have emerged. Similar patterns developed at the Workshop on the Commercialization of Chemical Sensors for Environmental Applications where a group of industry experts independently ranked market needs by sales potential.

The workshop participants attempted to rate the various needs by market potential and other factors based on their knowledge and experience. Participants noted that it was difficult to estimate the market potential for each need, as consideration of each need required consideration of elements such as detection limits and related applications. One participant observed that as discussion on each need continued, it seemed the number of other considerations mentioned seemed to grow geometrically. Overcoming these difficulties, the participants did manage to arrive at a set of needs rankings.

Participants were divided into seven groups, and each group identified the highest needs which applied to their area in terms of market potential. A summary of the results of this process are shown.

Air Quality Monitoring Top Needs
Monitoring individual organics in air
Detecting individual organics in air

Containment Monitoring Top Needs
Monitoring individual organics in soil in-situ
Monitoring individual organics in water in-situ
Monitoring individual organics in soil

Effluents Monitoring Top Needs
Detecting individual organics in water/ liquids
Detecting individual RCRA metals in water

Process Monitors and Control/ Resource Recovery Top Needs
Monitoring individual organics in water
Monitoring individual RCRA metals in water

Subsurface Characterization Top Needs
Detecting individual organics in soil in-situ
Detecting individual organics in water in-situ

Detecting individual organics in soil

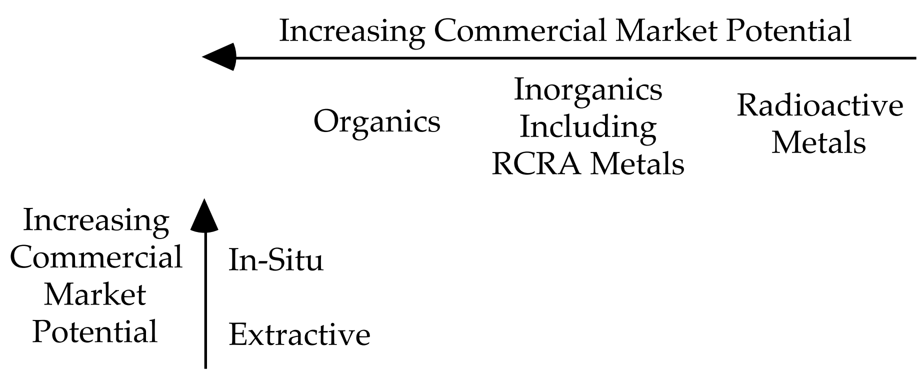
Surface Decontamination for Decontamination & Decommissioning Applications Top Needs
Detecting individual radioactive metals in metal, concrete, other solids
Detecting individual radioactive metals in asbestos

Waste Characterization Top Needs
Detecting individual radioactive metals in sludge
Detecting individual radioactive metals in waste drums and boxes non-destructively
Detecting individual radioactives in high level waste tanks in-situ
Detecting RCRA metals in waste drums and boxes non-destructively
Detecting individual organics in air in-situ

Based on the market potential needs ranking, and the top needs identified in the Workshop groups, two trends were observed. First, organics are the pollutants with the highest market potential, followed by inorganics including RCRA metals, with radioactive metals having the lowest market potential. Second, the ability to perform analysis in-situ has a higher commercial potential than equipment which requires extractive sampling after considering the cost of sample collection. These observations are logical based on the types and levels of contamination found at hazardous waste sites throughout the U. S.

The patterns which emerged from the needs ranking conducted in this study and at the Workshop are summarized below.

Market Potential Trends for Market Needs



Differences between detecting contaminants in different matrices did not show a clear pattern.

Each of these needs should be further defined along a series of technical requirements in order to be more meaningful for technology users, and equipment developers. Based on the discussions at the Workshop, the relative size of the market potential for a need is more meaningful to technology developers than technology users, although there are implications for both.

The market potential of a technology need does not have a direct impact on most equipment users. If a need has a large market potential, then technology developers are presumably working toward developing products to meet the individual user's need. On the other hand, difficult technical and regulatory hurdles may exist to profitably develop some technologies. In the case of significant obstacles, the user may choose to participate in the technology development in order to meet his own need. If the need has a very small market potential, then a user can not rely on market forces to drive technology development. In the case of a small market potential, a user with a pressing need may need to participate in the technology development process. On the other hand, a small potential for the environmental field instrument market combined with a large potential for a related market may be sufficient to drive vendors to develop new technology.

The implications of a need's market potential on an individual technology developer varies with the size of the technology developer. A relatively large technology developer has the resources to identify specific market potentials, and to finance technology development. Large technology developers tend to identify and pursue large market potentials with relatively low technical risks. Small technology developers look for clear market potentials which may be met by their technical expertise. If the market potential is large, a small technology developer may seek venture capital to develop their technology to meet the need. If the market potential is small, a small technology developer may approach individual equipment users to support the technology for their individual need.

If the market potential is small, neither a large nor small technology developer will be willing to independently develop technology to meet the need. When the overall market potential is small, a small technology developer is often *more* willing to meet the market need than a large company. A small company would be eager to apply their technical expertise to develop a specialized instrument for an individual user for a relatively low cost. Larger technology developers are oriented to producing a large number of devices and servicing a large number of customers, and show little interest in developing a specialized instrument for a single user.

The implications of the market potential of a need on technology development are summarized in the table on the following page.

Sources of Funding for Technology Development

	Large Developer	Small Developer
Large market potential Low technical risk	Self-finance	Venture capital
Large market potential High technical risk	Special development contract	Special development contract
Small market potential	Low interest in user-financed special contract	High interest in user-financed special contract

This market study has discussed a variety of topics which pertain to the current and future state of environmental field analysis. The findings of these discussions conclude this report in the next section.

Conclusions

Based on the information gathered in equipment user surveys and secondary research, the analysis of the market for environmental field instrumentation in the U. S. has resulted in the following findings:

Niched Market

The market for environmental field instruments consists of many niched applications which are met by a number of different technologies. For example, measuring metals in water can be done by X-Ray Fluorescence analyzers, or possible an Immunoassay kit.

Expanding Market

The market for environmental field instruments has been expanding due to increased hazardous waste site characterization, cost savings from on-site analysis compared to off-site analysis, and improved regulator and customer acceptance of on-site methods. The market will continue to expand with increasing acceptance and technology developments, displacing off-site laboratory analysis and related expenses.

Unreachable Maximum Potential

Field instruments will never completely replace laboratory analysis, and therefore never realize its maximum market potential. Realistically, the market should enjoy an average of 7% growth annually for the foreseeable future.

Market Overlap

The market for environmental field instruments overlaps with other markets, such as for chemical industry process monitoring. The potential for overlap with a variety of other industrial applications will contribute to the development of technology to meet many market needs.

Many Market Needs

The needs in the market paralleled the chemicals most commonly used by industry and government which have resulted in contamination -- organics, inorganics, metals, and radioactive metals in soil, water, and air.

Varying Needs Potential

The market potential for each of the market needs paralleled the size of the problem both in terms of the degree of contamination, and the technical challenges faced. More extensive contamination translates into a larger market need. In general, sensors for detecting organics have a larger than average market potential, and sensors for detecting radioactive metals have a smaller than average market potential. Due to the expense of extracting samples, and the challenges of in-situ measurement, in-situ instruments have a larger market potential than extractive devices.

Implications for Technology Development

Market forces of a large market potential and low technical risk will drive technology development by technology developers. Development of equipment for a small market or with a high technical risk will likely require participation and support from equipment users.

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